CHAPTER 14

DIRECT LEVELING AND BASIC ENGINEERING SURVEYS

Leveling is an operation that is used for determining the elevations of points or the differences in elevation between points on the earth's surface. This operation is extremely vital for deriving necessary data required for various engineering designs, mapping, and construction. Data from a finished level survey are used to (1) design roads, highways, and airfields; (2) develop maps, showing the general configuration of the ground; (3) calculate volume of earthwork; and (4) lay out construction projects.

In this chapter, we discuss the basic principles of DIRECT LEVELING and the types of methods used; the duties and responsibilities of the leveling crew; field procedures used in differential leveling; precision in leveling; and proper ways of handling leveling instruments and equipment. INDIRECT LEVELING, such as barometric and trigonometric leveling, adjustment of level network, and end areas and volume of earth's computations, is not covered in this book.

In this chapter, you will find a general description of basic engineering surveys and various construction-site safety hazards commonly associated with the EA survey party. Other types of engineering and construction surveys—particularly those for curves and earthwork—will be presented at the EA2 level.

BASIC TERMS USED IN LEVELING OPERATIONS

Generally, the basic vertical control for topographic survey and mapping is derived from first- and second-order leveling. For many construction projects and for filling gaps between second-order bench marks (BMs), less precise third-order leveling is acceptable.

In leveling, a level reference surface, or datum, is established, and an elevation is assigned to it. This datum may be assigned an assumed elevation, but true elevation is required for the establishment of a BM. A series of properly established BMs is therefore the framework of any vertical control.

Although further discussion will follow, fundamentally, direct leveling describes the method of measuring vertical distances (differences in elevation) between the plane of known or assumed elevation (datum) and the plane of a point whose elevation you are seeking. Once these distances are known, they may be added to, or subtracted from, the known or assumed elevation to get the elevation of the desired point. These vertical distances are obtained by use of a leveling rod and, usually, an engineer's level.

Some of the basic terms commonly used in leveling operations are defined in the following paragraphs.

BENCH MARK

ABM is a relatively permanent object, natural or artificial, bearing a marked point whose elevation is known. BMs are established over an area to serve as (1) starting points for leveling operations so the topographic parties can determine other unknown elevation points and (2) reference marks during later construction work. BMs are classified as PERMANENT or TEMPORARY. Generally, BM is used to indicate a permanent bench mark and TBM, to signify a temporary bench mark. TBMs are established to use for a particular job and are retained for the duration of that job. Throughout the United States, a series of BMs have been established by various government agencies. These identification markers are set in stone, iron pipe, or concrete

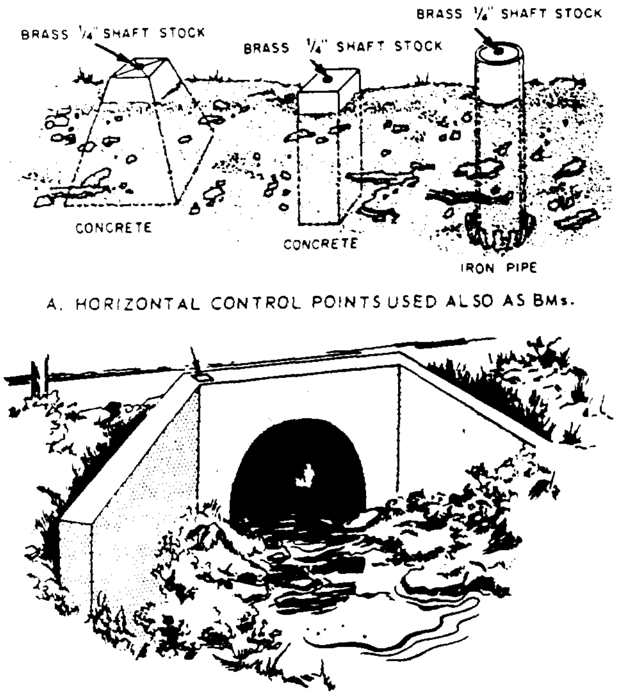


Figure 14-1.-Common types of bench mark construction and application.

and are generally marked to show the elevation above sea level. When the elevation is not marked, you can find out what it is by contacting the government agency that originally set the BM. Just be sure you give them the same identification number as the one on the marker. The type of standard bronze markers used was discussed in chapter 11 of this training manual.

BMs may be constructed in several ways. Figure 14-1, view A, shows brass shaft stocks in the tops of permanent horizontal control points (monuments). Sometimes, monuments of this type are also used for vertical control BMs. Original BMs may be constructed in the same manner. When regular BM disks are not available, brass, not steel, 50-caliber empty shell casings may be used. The shank of the empty shell casings should be drilled crosswise and a nail inserted to prevent its being pulled out or forced out by either expansion or contraction.

For short lines and a level circuit of a limited area, any substantial object may be used for vertical control BMs. The remark in the field notes should bear the proper identification of the BMs used.

Figure 14-1, view B, shows a mark like those commonly used on tops of concrete walls, foundations, and the like. Lines are chiseled out with a cold chisel or small star drill and then marked with paint or keel. The chiseled figures should be about the same size as the base area of the rod. Preferably, they should be placed on some high spot on the surface of the concrete structure.

A spike may be driven into the root of a tree or placed higher up on the trunk of the tree when the limb clearance allows higher rod readings. Figure 14-2, view A, shows the recommended way to do this. The rod should be held on the highest edge of the spike, and the elevation should be marked on the blazed portion of the tree. Figure 14-2, view B, shows a spike driven on a pole or post that also represents a BM. Drive the spike in horizontally on the face of the post in line with the direction of the level line. For the reading, hold the rod on the uppermost edge of the spike. After the elevation has been figured, mark it on the pole or post for future reference.

Stakes driven into the ground can also be used as TBMs, especially if no frost is expected before they are needed. A detailed description of these points is just as important as one for a monument station.

In most permanent military installations, monument BMs are established in a grid system approximately one-half mile apart throughout the base to have a ready reference for elevations of later construction in the station. Generally, these BMs are fenced to mark their locations. The fence also serves to protect them from being accidentally disturbed.

BM systems or level nets consist of a series of BMs that are established within a prescribed order of accuracy along closed circuits and are tied to a datum. These nets are adjusted by computations that minimize the effects of accidental errors and are identified as being of a specific order of accuracy.

In certain areas, TIDAL BENCH MARKS must be established to obtain the starting datum plane or to check previously established elevations. Tidal bench marks are permanent BMs set on high ground and are tied to the tide station near the water surface.

Tide stations are classified as primary and secondary. Primary stations require observations for periods of 19 yr or more to derive basic tidal data for a locality. Secondary stations are operated over a limited period (usually less than 1 yr) and for a specific purpose, such as checking elevations. The secondary station observations are always compared to, and computed from, data obtained by primary stations.

A tide station is set up, and observations are made for a period that is determined by a desired accuracy. These observations are compared with a primary tide station in the area and, then, are furnished with a mean value of sea level in the area.

A closed loop of spirit levels is run from the tide station over the tidal BMs and is tied back to the tide station. The accuracy of this level line must be the same as or higher than the accuracy required for the BMs.

For permanency, tidal BMs usually are set in sets of three and away from the shoreline where natural activity or future construction probably will not disturb or destroy them.

DATUM

Tidal datums are specific tide levels that are used as surfaces of reference for depth measurements in the sea and as a base for determining elevations on land. In leveling operations, the tidal datum most commonly used is the MEAN SEA LEVEL. Other datums, such as mean low water, mean lower low water, mean high water, and mean higher high water, are sometimes used, depending upon the purpose of the survey. Still other datums have been used in foreign countries. When conducting leveling operations overseas, you should check into this matter carefully to avoid mistakes.

Mean Sea Level

Mean sea level (MSL) is defined as the average height of the sea for all stages of the tide after long periods of observations. It is obtained by averaging the hourly heights as they are tabulated on a form similar to that

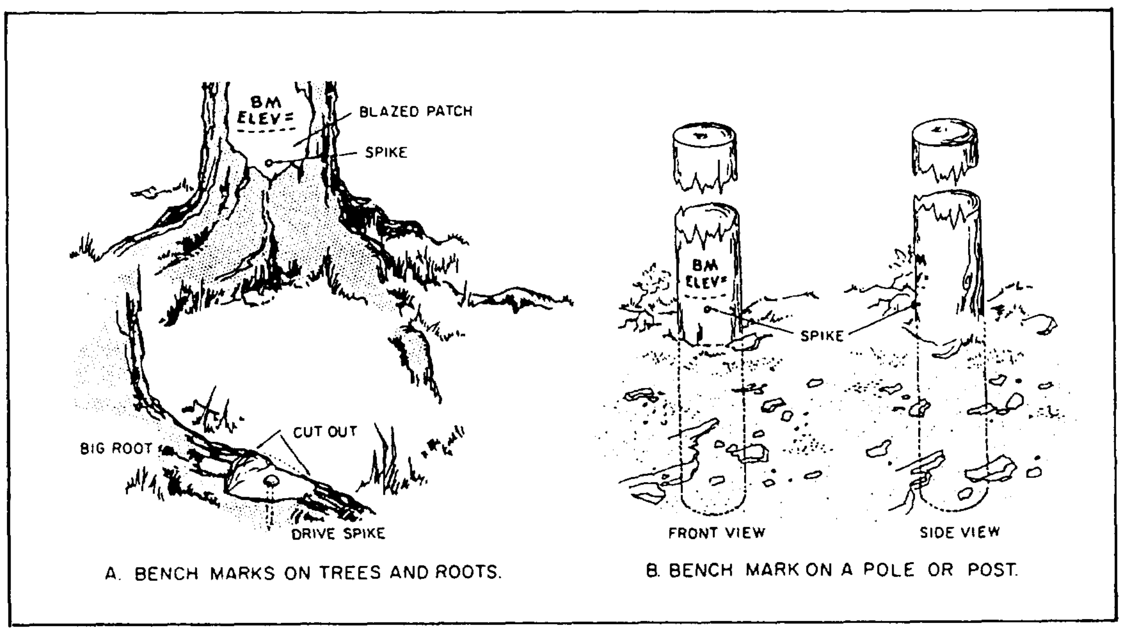


Figure 14-2.-Ways of using spikes as bench marks.

Day & Mo.	1 Mar.	2	3	4	5	6	7	Sum	Remarks:		
Hour 0	15.1 Ft.	15.5 Ft.	15.4 Ft.	13.9 Ft.	12.0 Ft.	9.0 Ft.	6.6 Ft.	87.5 Ft.	Tides: Hourly Heights		
1	14.4	15.7	16.6	15.9	14.8	12.1	9.5	99.0	Station: Portsmouth		
2	13.5	15.4	17.0	17.3	17.1	15.1	12.8	108.2	Lat. 44° 50' N		
3	12.5	14.8	16.9	17.9	18.6	17.5	15.8	114.0	Long. 68° 10' W		
4	11.7	14.0	16.5	17.8	19.2	19.0	18.0	116.2	Party Chief EA2 Long		
5	11.6	13.3	15.7	17.3	19.1	19.6	19.4	116.0	Tide Gage No. 85		
6	12.3	13.2	14.9	16.4	18.5	19.5	19.8	114.6	Scale 1:24		
7	13.7	13.7	14.6	15.5	17.4	18.7	19.5	113.1	Tabulated by EA3 Smith		
8	15.4	15.0	15.0	15.0	16.3	17.6	18.6	112.9			
9	17.6	16.5	15.9	15.2	15.6	16.3	17.1	114.2			
10	19.2	18.2	17.2	16.0	15.8	15.6	15.9	117.9			
11	20.1	19.4	18.5	17.2	16.6	15.6	15.1	122.5			
12	19.9	19.8	19.4	18.4	17.7	16.3	15.4	126.9			
13	19.0	19.3	19.7	19.2	18.7	17.5	16.2	129.6			
14	17.3	18.0	18.9	19.2	19.5	18.4	17.3	128.6			
15	15.0	15.9	17.3	18.2	19.4	19.0	18.3	123.3			
16	12.2	13.1	14.8	16.3	18.1	18.6	18.9	112.0			
17	10.3	10.5	11.8	13.6	15.9	17.1	18.4	97.7			
18	9.5	8.5	9.2	10.5	13.0	14.7	16.8	82.2			
19	9.7	7.8	7.4	7.8	9.8	11.5	14.1	68.1			
20	10.5	8.3	6.7	6.1	7.0	8.1	10.9	57.6			
21	11.8	9.5	7.5	5.8	5.3	5.6	7.8	53.3			
22	13.4	11.4	9.1	7.0	5.1	4.2	5.4	55.6			
23	14.8	13.6	11.4	9.1	6.6	4.6	4.2	64.3			
Sum	340.5	340.4	347.5	346.6	357.1	351.2	352.0	2435.3			

Figure 14-3.–Sample format showing hourly heights of tide required for computing average mean sea level (MSL).

shown in figure 14-3. The heights on this form are added both horizontally and vertically. The total sum covering 7 days of record is entered in the lower right-hand corner of the page. The mean for each calendar month is found by combining all daily sums for the month and dividing by the total number of hours in the month. The monthly mean, to two decimal places, is entered on the sheet that includes the record for the last day of the month. Yearly means are determined from the monthly means, and a mean is taken of all yearly means for the period of record. Three or more years of record should be used for a good determination of sea level. The actual value varies somewhat from place to place, but this variation is small. The station used for MSL determinations should be on the open coast or on the shore of bays or harbors having free access to the sea. Stations on tidal rivers at some distance from the open sea will have a MEAN RIVER LEVEL that is higher than mean sea level because of the river slope. It should be noted that mean sea level is NOT identical with mean tide level (MTL). The latter is derived from the mean of all high and low points on the tidal curve. But MSL is derived from the mean of a much larger number of points taken at hourly intervals along the tidal curve.

The datum universally used in leveling is mean sea level (MSL), and it is considered to be the zero unit. The vertical distance of a given point above or below this datum then becomes the elevation of that point.

Other Datums

Along the Atlantic coast of the United States, the mean low water (MLW) datum has been generally adopted as the datum used for hydrographic surveys. It is the mean of all low water tides observed over a long period (usually a 19-yr period). Mean lower low water (MLLW) has been generally adopted for hydrographic surveys along the Pacific coast of the United States, Hawaii, Alaska, and the Philippine Islands. It is the mean of the lower of the two low water tides for each day observed over a long period. Mean low water spring (MLWS) is used on the Pacific coast of the Panama Canal Zone. It is defined as the mean of the low waters of the spring tides occurring a day or two after a full moon and is obtained by subtracting one-half of the range of the spring tides from the mean sea tide level.

LEVEL PARTY ORGANIZATION, EQUIPMENT, AND FIELD PROCEDURES

Certain basic preparations relative to the magnitude and complexity of the job must be performed before any leveling survey is undertaken. Proper planning and thorough identification of the procedures to be followed in all phases of the work are essential to the success of the leveling operation. Participating in this preparatory work will also enhance the experience and increase the capabilities of the crew members. Some of the preparations you must be familiar wit h are discussed in the next several paragraphs.

LEVEL PARTY ORGANIZATION

The size of your leveling party will depend upon such variables as the order of accuracy required and the number of experienced personnel available. Ordinarily, the smallest crew may consist of two individuals: an instrumentman and a rodman. To improve the efficiency of the leveling operations, additional personnel are required. The addition of a second rodman to alternate on backlights (BSs) and foresights (FSs) will speed up leveling. If you add a recorder, the instrumentman will be able to take readings as soon as the rodmen are in position. In surveys requiring a shaded instrument, an umbrellaman is required.

Duties of the Instrumentman

An instrumentman, or levelman, runs the level and makes adjustments required for proper operation. He makes certain that no stations are omitted, that turning points (TPs) are properly selected, and that BMs are properly established and identified. The levelman is usually designated by the EA1 or EAC to act as the chief of the party. When a two-man leveling party uses a self-reading rod, the levelman is also the recorder. However, if a target rod is used, the rodman usually acts as the recorder. A good levelman keeps within the required limits of error.

As chief of the party, you must be alert to recognize common problems encountered in the field and be able and ready to solve them using the best solution. Your sound judgment and proper course of action in handling these field problems will influence the quality of your survey and the meeting of your survey schedules.

Handling Leveling Instruments and Equipments

Leveling instruments, as well as all surveying instruments and equipments, have to be accorded the care and proper handling that any delicate instrument merits. Give special attention to prevent sudden shocks, jolts, and bumps, which will cause retesting of the instrument to be required. A damaged or disturbed scientific instrument, however minor, will adversely affect correct and accurate results. As a rule, a visual inspection for signs of physical damage of the instrument is to be conducted before each use.

An engineer's level is a precision instrument containing many delicate and fragile parts. Movable parts should, when not locked in place, work easily and smoothly. When a part resists movement, there is something wrong; if you force the part to move, you are quite likely to damage the instrument. You will also cause damage by wear if you use excessive force in tightening clamps and the like.

To ensure easy movement, keep threads and bearing surfaces on movable parts lubricated. For the same reasons, these parts have to be kept clean. Always clean the parts before oiling them. When oiling the parts, use only fine instrument oil; and do not use too much of it. An excess of oil gathers dust and also thickens, which will interfere with free movement of the parts. This is especially true in cold weather because low temperatures cause oil to congeal. In cold weather, graphite powder is a more suitable lubricant than oil.

Keep the level in its case when it is not in use and when you are transporting it to and from the jobsite. The level screws and the clamp screws should be tightened just enough to prevent motion of the parts inside the case. The instrument case is designed to reduce the effect of jarring and is strongly made and well padded to protect the level from damage. When transporting the level by vehicle, you should place the carrying case about midway between the front and rear wheels. This is the point at which the bouncing of the wheels has the minimum effect.

Never lift the instrument out of the carrying case by grasping the telescope; wrenching the telescope in this manner could damage a number of delicate parts. Always lift the instrument out of the case by grasping the footplate or the level bar.

When the instrument and the tripod are to be carried from one setup point to another, loosen

Figure 14-4.-Recommended carrying position of instrument when obstacles may be encountered.

the level and clamp screws slightly. They should be tight enough to prevent the telescope from swinging and the instrument from sliding on the footplate, but loose enough to allow a “give” in case of an accidental bump against an obstacle.

When you are carrying the instrument over terrain that is free of possible contacts (for example, across an open field), you may carry it over your shoulder like a rifle. But when obstacles may be encountered, carry the instrument under your arm, as shown in figure 14-4.

To avoid the effects of sunlight, you should use a surveyor’s umbrella or the like. If there is any great difference between the working and storage temperature, the instrument should be allowed to adjust itself to the actual working conditions for about 15 min before observations are started.

Duties of the Rodman

The rodman must hold the leveling rod properly in order to sight on it or read it accurately. This is the rodman’s responsibility. The actions of a rodman in positioning and holding the rod will affect the speed and accuracy of the leveling operation, so if you are the rodman, use extreme care. It is also the rodman’s responsibility to take care of the rod during and after the leveling operation. Your duties as a rodman are as follows:

1. Clean the base (or shoe) of the rod before setting the rod on any point. Also, clean the top of the point to ensure good contact between the rod and the point.

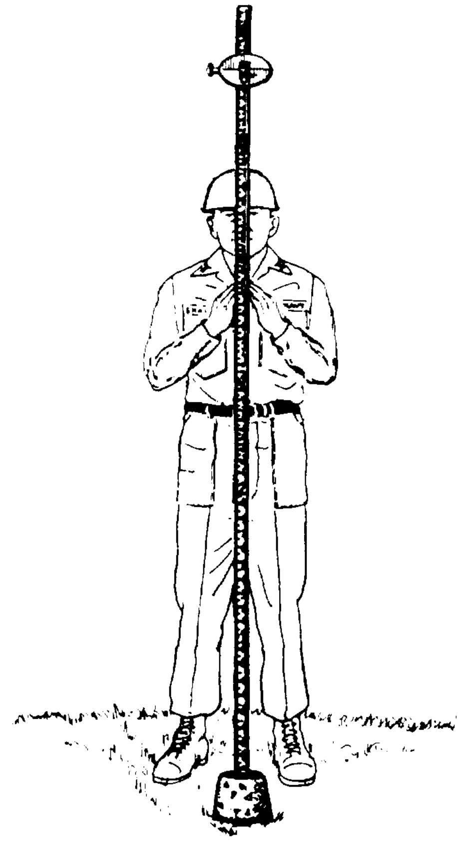


Figure 14-5.-Proper stance for holding a level rod on a bench mark while facing the instrument.

2. Place the rod firmly on the point; then stand facing the instrument and slightly behind the rod; hold the rod in front of you with both hands (fig. 14-5). Space your feet about 1 ft apart for a comfortable stance. Also, make sure that the graduations of the rod are right side up and are turned towards the instrumentman.

3. Hold the rod as nearly vertical as possible, then place a rod level against the rod, and move the top end of the rod until the bubbles are centered. If you do not use a rod level, balance the rod by using your fingertips to prevent it from falling. A properly balanced rod will stand for several seconds before starting to fall. This process of balancing the rod vertically is known as PLUMBING THE ROD.

4. Plumb the rod and hold it as steady as possible during strong winds. When this condition exists, the instrumentman may call for you, as the rodman, to WAVE THE ROD. Wave the rod by pivoting it on its base and swinging it in a slow arc toward the instrument and away. Keep the shoe firmly seated during this operation. The

motion of the rod permits the instrumentman to read the rod when it reaches a vertical position at the top of the arc and when the lowest reading appears on the rod. Before or after the rod is in this vertical position, the rod reading is greater.

5. Set the turning pin or pedestal firmly in contact with the ground when setting a TP. Any unfirm footing can sag under the weight of the rod and result in incorrect readings between the FS and BS. During freezing and thawing weather conditions, the ground surface can heave in a comparatively short time. Pins and pedestals can be affected by the heave between the FS and the following BS. For higher order of accuracy surveys, you should be aware of this possibility and select firm locations.

6. Extend the leveling rod to its maximum length when the instrumentman calls for extending the rod. The standard Philadelphia leveling rod can be read to 7.100 ft or 2.164 meters when collapsed and 13.000 ft or 3.962 meters when extended. An extended leveling rod is called a LONG ROD.

A leveling rod is a precision instrument and has to be treated with care. Most rods are made of carefully selected, kiln-dried, well-seasoned hardwood and have metal scale faces on which the scale graduations are painted. Unless a rod is always handled with great care, the painted face will become scratched, dented, or damaged in other ways. Accurate readings on a rod that is damaged are difficult.

Letting an extended rod close “on the run” by allowing the extended upper section to drop tends to damage both sections of the rod and to displace the vernier. Always close an extended rod by easing down the upper section.

A rod will read accurately only if it is perfectly straight, so you must avoid anything that might bend or warp the rod. Do not lay a rod down flat unless it is supported throughout on a flat surface. Do not use a rod as a support or as a lever. Store the rod in a dry place to avoid any possible warping and swelling from dampness, and always wipe a wet rod dry before stowing it away.

If there is mud on the rod, rinse it off, but do not scrub it. If you have to use a soap solution to remove grease, use a mild solution. Repeated washings with strong soap solutions will eventually cause the painted graduations to fade.

FIELD PROCEDURES FOR DIFFERENTIAL LEVELING

Leveling operations require the teamwork of both the instrumentman and the rodman to achieve consistent results. The accuracy of the survey depends upon the refinement with which the line of sight can be made horizontal by the instrumentman, the ability of the rodman to hold the rod vertically, and the precision with which the rod reading is made. Some of the basic procedures and preparations applicable to direct leveling are presented below.

Selecting Setup Points

Terrain and atmospheric conditions are the main considerations affecting the selection of setup points. It is essential that you select a point from which you can best observe a rod reading on the BS and FS points. In the interest of balanced shots, a setup point should be about equidistant from both BS and FS. In addition, shorter setup distances will result in smaller instrument errors caused by the atmospheric refraction and curvature of the earth.

The average instrument height at any setup is about 5 ft (1.5 m). On even downhill slopes, the ground where the instrument is set up may not be more than 3 to 5 ft below the TP for a level BS. On the FS, the extended rod can be held on the ground about 8 ft (2.5 m) below the instrument ground level and still permit a reading to be taken. This means that the tendency will be to make FS distances longer going downhill and to make BSs longer going uphill.

Therefore, it is necessary to conduct a reconnaissance of the terrain before you start leveling. You should note probable locations of instrument setup and TPs. During the reconnaissance, you should estimate the line of sight by sighting through a hand level.

Setting Up a Level

In setting up the tripod, you first hold two tripod legs with both hands and spread the tips of these legs a convenient distance apart. Then bring the third leg to a position that approximately levels the top of the protector cap when the tripod stands on all three legs. Then unscrew the protector cap.

Next, you lift the instrument out of the carrying case by the footplate or level bar, NOT by the telescope, and set it gently and squarely on the tripod head threads. Rotate the footplate counterclockwise one-fourth turn or until the instrument seats itself; then rotate it clockwise to engage the head nut threads to the tripod head threads. If the threads do not engage smoothly, they are cross-threaded. Do not force the head if you encounter resistance, but back it off, square up the instrument, and try again gently to engage the threads. When they engage, screw the head nut up firmly but not too tightly. Setting up the instrument too tightly causes eventual wearing of the threads, making unthreading difficult.

After you have attached the instrument, if you are set up on stable soil, thrust the tripod legs' tips into the ground far enough to be sure of a stable support, taking care to keep the footplate approximately level. Some tripods have legs equipped with short metal stirrups. These stirrups allow you to force the legs' tips into the ground by foot pressure.

If you are set upon a hardened surface, such as concrete, make sure the tripod legs do not accidentally spread, causing the tripod to collapse. In figure 14-6, view A, the legs' tips are inserted in cracks in a concrete pavement. In figure 14-6, view B, they are held by an equilateral wooden triangle called a floor triangle.

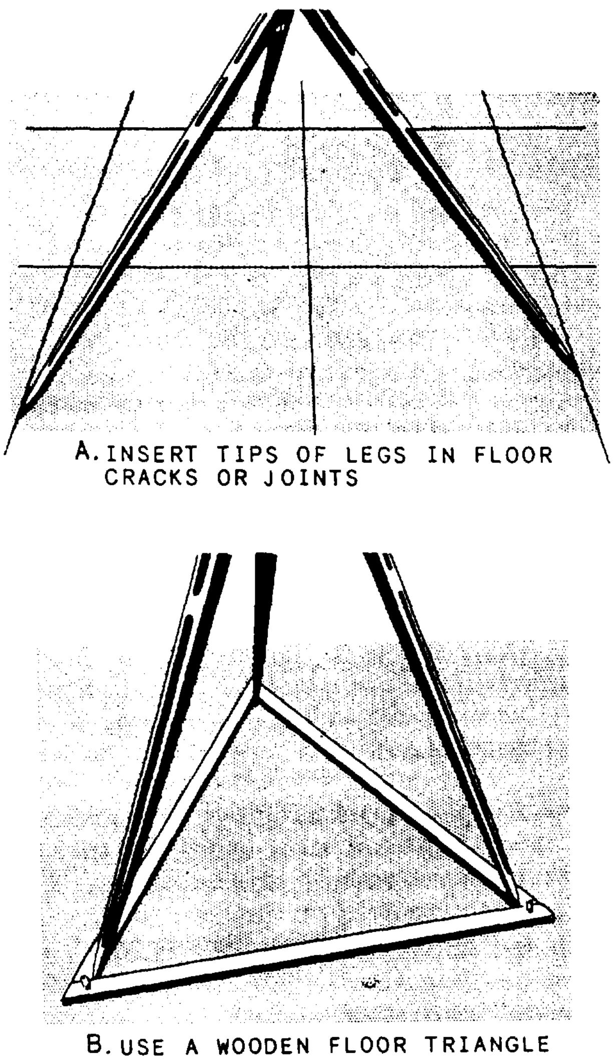


Figure 14-6.-Two ways of preventing tripod legs from spreading on hardened surface.

Leveling the Engineer's Level

As a rodman, you must concentrate on keeping your rod perfectly plumb. Readings on a rod that is out of plumb are inaccurate. Similarly, as a levelman, you must constantly bear in mind that the line of sight through the telescope must be perfectly level in every direction or every reading you make with the instrument will be inaccurate. After you initially place the instrument, level it carefully as follows:

Train the telescope in line with a pair of level screws and manipulate the level screws by turning them in opposite directions, as shown in figure 14-7, until the bubble in the level vial is in the exact center. It is helpful to know that the bubble in the level vial will move in the direction that your left thumb moves. To put this another way: When you turn the left-hand screw clockwise, the bubble moves to your left; when you turn the left-hand screw counterclockwise, it moves to your right.

When the bubble is centered with the telescope over one pair of screws, train the telescope over the other pair and repeat the process. As a check, swing the telescope over each pair of screws in all four possible positions to make sure the bubble is centered in each position.

Making Direct Readings

The instrumentman makes a direct rod reading as viewed directly on the graduation of the rod (self-reading) that is in line with the horizontal

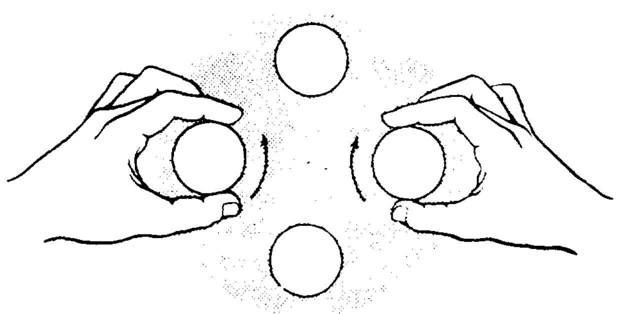


Figure 14-7.-Manipulating level screws.

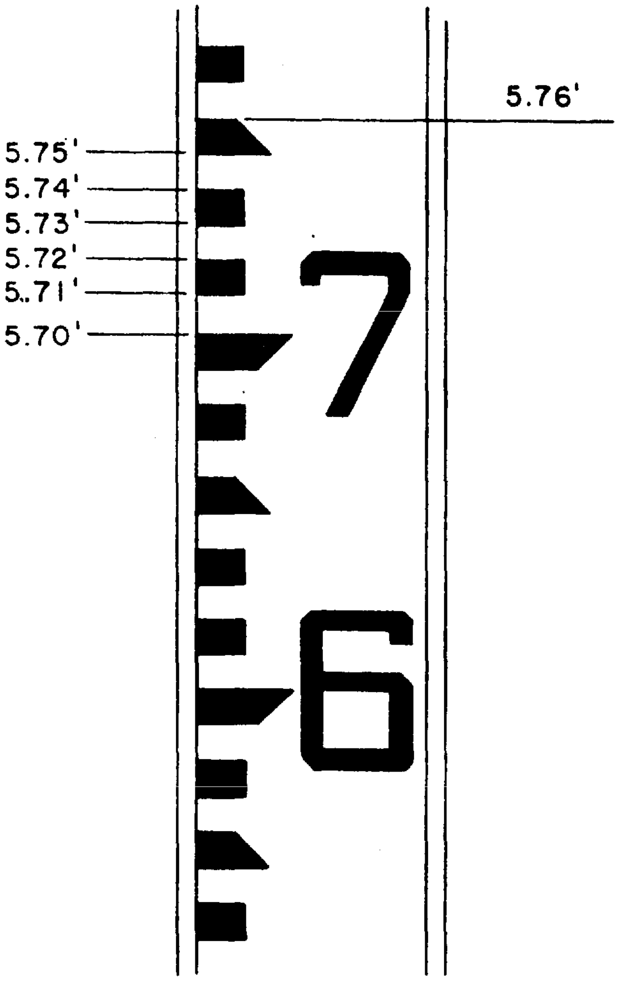


Figure 14-8.-Showing a direct reading of 5.76 ft on a Philadelphia rod.

cross hair. A rod other than an architect's rod is usually graduated in feet subdivided to the nearest 0.01 ft; therefore, direct readings are possible only to the nearest 0.01 ft.

Figure 14-8 shows a direct reading of 5.76 ft on a Philadelphia rod. You can see that each black graduation and each white, interval represents 0.01 ft.

You can see also that the black figure 7 is the only numeral of the reading 5.76 ft that appears in the view. The red numeral 5 would not be visible through the telescope unless the sight distance was quite far away. For this reason, you would signal the rodman to "raise for red," as described in the previous chapter.

To make sure you relate the reading for tenths and hundredths to the correct whole-foot red numeral, it is best to make a direct reading as follows: When the horizontal cross hair and the rod are brought into clear focus, first determine the number of hundredths. Then, read the next lower black figure for the tenths. Finally, signal for a "raise for red," and note the number of whole feet.

Making Target Readings

The three most common situations in which target readings rather than direct readings are made are as follows: (1) when the rod is too far from the instrument to be read directly; (2) when you desire a reading to the nearest 0.001 ft, which requires the use of the vernier by the rodman; and (3) when the instrumentman thinks a reading by the rodman instead of by himself more likely will be accurate.

For target readings up to 7.000 ft, the Philadelphia rod is used fully closed and read on the face by the rodman. The rodman sets the target on the face by the signals from the instrumentman, who determines when the horizontal axis of the target intercepts the horizontal cross hair.

When the instrumentman signals "all right," the rodman clamps the target in place with the target screw clamp, as shown in figure 14-9; then

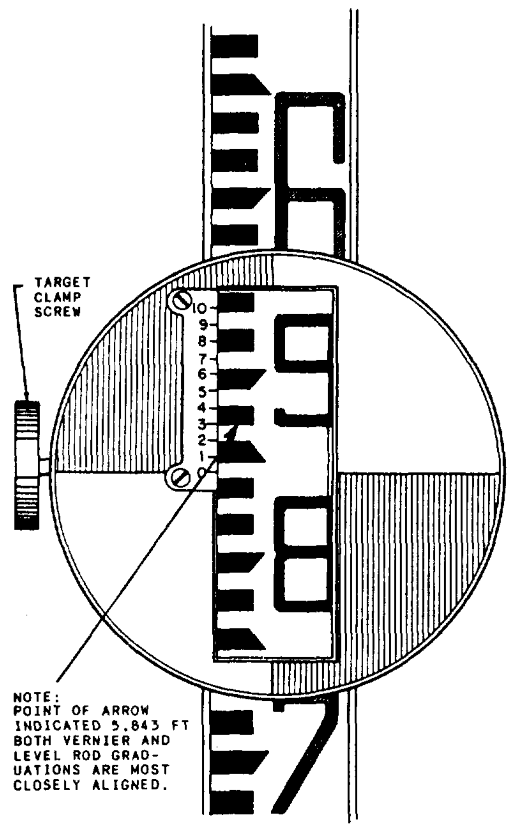


Figure 14-9.-Target reading of 5.843 ft on a Philadelphia rod.

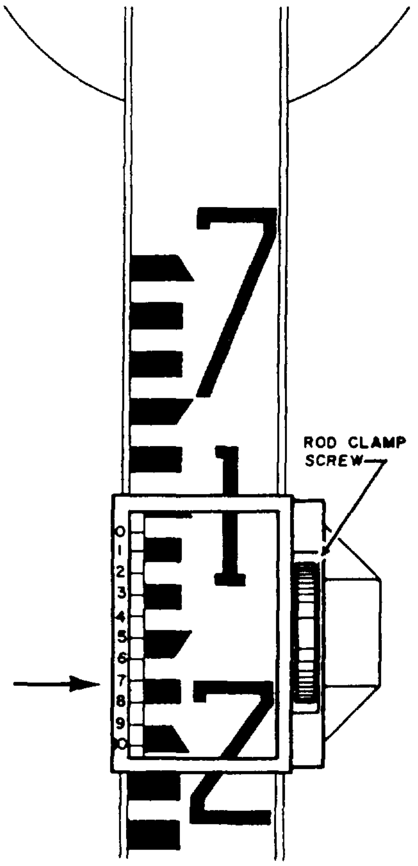


Figure 14-10.-Reading of 7.107 ft on back of Philadelphia rod as indicated by arrow.

the rodman reads the target vernier, shown in the same figure.

The reading to the nearest 0.01 ft is indicated by the zero on the vernier. In figure 14-9, the vernier zero indicates a reading of a few thousandths of a foot more than 5.84 ft. To determine how many thousandths over 5.84 ft, you examine the graduations on the vernier to determine the one most exactly in line with a graduation on the rod. In figure 14-9, this is the 0.003-ft graduation; therefore, the reading to the nearest 0.001 ft is 5.843 ft.

For target readings of more than 7.000 ft, the Philadelphia rod is used extended; the rodman makes the reading on the back of the rod. In figure 14-10, the back of the upper section of the rod is shown, graduated FROM THE TOP DOWN, from 7.000 ft through 13.000 ft. You can also see a rod vernier on the back, fixed to the top of the lower section of the rod, also reading from the top down.

For a target reading of more than 7.000 ft, the rodman, on receiving the signal to "extend the rod," fixes the target on the face of the upper section all the way to the top of the upper section. While doing this, the rodman makes sure the target vernier is set at exactly the same reading indicated by the rod vernier on the back of the rod, He then releases the rod screw clamp and slides the upper section of the rod slowly upwards until the instrumentman gives the signal "all right." When the horizontal axis of the target reaches the level where it is intersected by the horizontal cross hair, the instrumentman gives this signal.

FUNDAMENTAL LEVELING PROCEDURE

Now that you have learned how to setup and level the engineer's level and how to read the leveling rod, let us take a look at an example that will explain the basic procedure of determining elevations during a leveling operation.

In figure 14-11, there is a BM at Point A with a known elevation of 365.01 ft. You wish to determine the elevation of a point on the ground at Point B. To do so, you first set up and level your engineer's level approximately half-way between Points A and B. When the instrument is leveled properly, you will have a perfectly level line of sight that can be rotated all around the horizon.

The next thing to do is to determine the elevation of this line of sight. This elevation is called the HEIGHT OF INSTRUMENT, familiarly known as the HI. To obtain this elevation, the instrumentman takes a backsight (BS) on a leveling rod held on the BM and, in this example, obtains a rod reading of 11.65 ft. The HI, then, is the BM elevation PLUS the rod reading, or 365.01 + 11.56, which equals 376.57 ft. This means that no matter to which direction the telescope is trained, any point around the horizon that is intercepted by the horizontal cross hair has an elevation of 376.57 ft.

To determine the ground elevation at Point B, the instrumentman now takes a foresight (FS) on a rod held at Point B. This time, a rod reading of 1.42 ft is read. Since the elevation of the line of sight (HI) is 376.57 ft, obviously the ground elevation at Point B is the HI MINUS the rod reading, or 376.57 – 1.42, which equals 375.15 ft.

Balancing Shots

The balancing of the FS and BS distances is important in leveling. The effeet of curvature and refraction may be eliminated by a balanced BS and FS distance; however, instrumental error is a far more important reason for careful balancing.

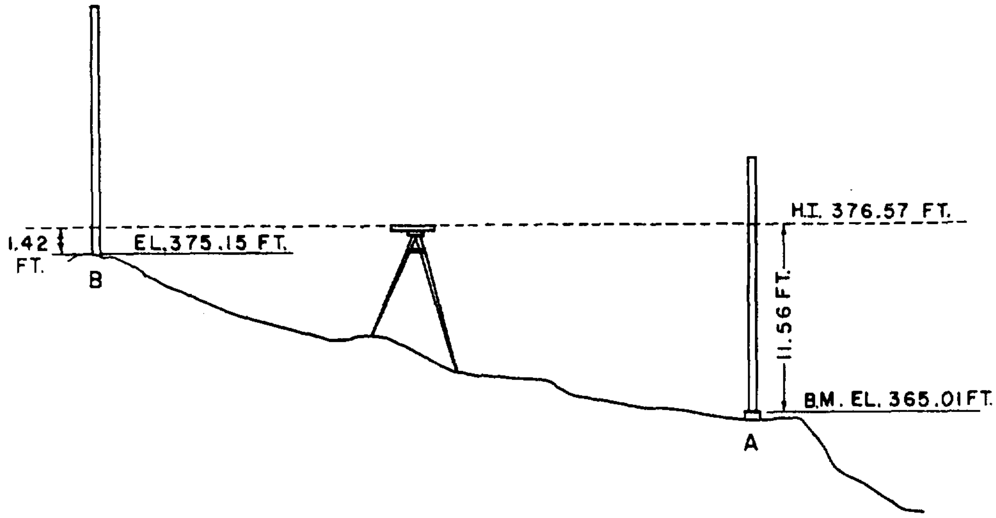


Figure 14-11.-Procedure for direct leveling.

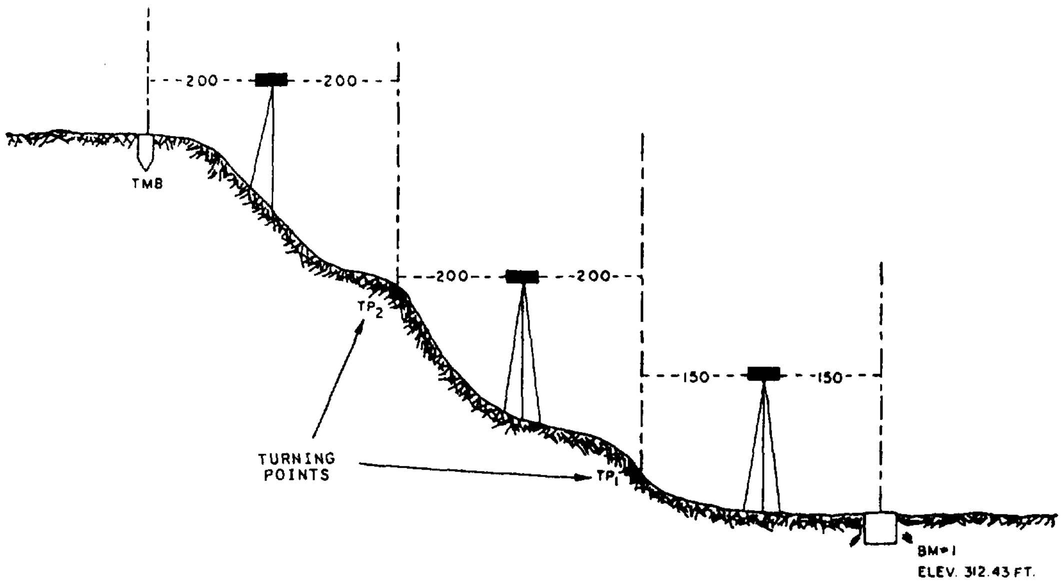


Figure 14-12.-Turning points.

"Balancing shots" means equalizing as much as possible BS and FS distances by selecting turning points that are approximately an equal distance from both the BS and FS points.

No matter how carefully you level a level telescope, it is likely to be still slightly out of the horizontal. The error this causes increases with the length of the sight taken. If the BS distance differs from the FS distance, the BS and FS errors will also differ. If the distances are the same, the errors will be the same. Balancing shots therefore eliminates the effect of instrumental error and also of curvature and refraction, other errors that increase with distance.

To balance distances for a setup, you will find that using the same number of paces for BS as for FS is helpful. In general, BS and FS distances should be kept under 300 ft except when necessary to pass or cross an obstacle.

Establishing Turning Points

Suppose you want to determine the elevation of a point at the summit of a long slope, and the nearest BM is at the foot of the slope some 30 ft or so below the summit. Obviously, you cannot sight a rod held on the BM and another held on the summit from the same instrument setup point. You must work up the slope in a series of steps, as shown in figure 14-12, by establishing as many intermediate TPs as you need to solve the problem. A "turning point" is defined as a point on which both a minus sight (FS) and a plus sight (BS) are taken on a line of direct levels.

As shown in figure 14-12, if we assume that the elevation of the BM is correct, the accuracy of the elevation you determine for the summit depends upon how accurately you determine the elevation of each intermediate TP. This accuracy depends upon a number of things, the most important of which are the following:

1. If you are doing leveling of ordinary precision, FS and BS distances should not exceed 300 ft. Therefore, the first setup point for the instrument should be not more than 300 ft from the BM, and the first TP should be not more than 300 ft from the instrument. To balance shots, you should place the instrument about the same distance from the BM as the distance to the TP.

2. Obviously, the first setup point must be one you can observe with a rod held on the BM and also a rod held on the first TP.

3. Generally, setup points should be used that make rod readings as small as possible. The reason small rod readings are desirable is that, for a rod held out of plumb, each reading on the rod will be in error. The larger the rod reading, the greater the error. Suppose, for example, a rod is so far out of plumb that it indicates 12.01 ft for a reading that should be 12.00 ft if the rod were plumb. For a 12.00-ft reading on the rod, the error is 0.01 ft. For a 2.00-ft reading on the same rod held in the same manner, however, the error would be only about 0.002 ft.

4. A TP must have not only visibility and accessibility, but also stability; that is, it must furnish a firm, nonsettling support for the base of the rod. Suppose you select a point in soft, yielding ground as your first TP. Assume the elevation of the BM is 312.42 ft. You take a BS on the BM and read 3.42 ft. Then, HI is

$$312.42 + 3.42 = 315.84 \text{ ft.}$$

The rodman shifts the rod to the TP. You take an FS and read 5.61 ft. The elevation of the TP is, therefore,

$$315.84 - 5.61 = 310.23 \text{ ft.}$$

Now, you shift the instrument ahead and take a BS to carry on the line of levels to a new TP.

But suppose that before you take the BS on the rod, the TP has settled 0.02 ft in the ground. Then you take a BS and read 4.74 ft. There is now an error of 0.02 ft in the new HI, and every subsequent HI and elevation of TP will be off by the same amount.

So BE SURE that each TP is stable. When the use of a point in yielding ground is unavoidable, you need to base the rod on a turning point pin or turning point plate. A pin is driven in the ground; if you don't have a regular pin, a marlinspike or a railroad spike makes a good substitute. You should use a plate on soil too soft to support a driven pin.

METHODS OF LEVELING

Leveling methods are subdivided into two major categories: DIRECT and INDIRECT. Direct leveling describes the method of measuring vertical distance (difference in elevation) directly with the use of precise or semi-precise leveling instruments. Indirect leveling methods, on the other hand, apply to measuring vertical distances indirectly or by computation. Unlike direct leveling operations, indirect leveling operations do not depend on lines of sight or intervisibility of points or stations. Some of the surveying instruments commonly used for indirect leveling methods are the transit and theodolite.

DIRECT LEVELING

This method of leveling uses the measured vertical distance to carry elevation from a known point to an unknown point. Direct leveling is the most precise method of determining elevation and yields accuracies of third or higher orders. When this method is specified for lower accuracy surveys, direct leveling is sometimes referred to as "spirit" or "fly" levels. Fly levels are leveling operations used to rerun original levels to make sure that no mistake has been made. Fly levels use a shorter route and smaller number of turning points than the original survey. Let's take a look at some of the processes involving direct leveling.

Differential Leveling

Differential leveling (also called direct leveling) is generally used in determining elevations of points to establish a chain or network of BMs for future use. It requires a series of instrument setups along the survey route; and for setup, a horizontal line of sight is established, using a sensitive level. The SEABEEs commonly use this type of leveling in determining elevation during construction surveys.

As shown in figure 14-13, the basic procedure used to determine elevations in a differential leveling operation is the same as previously discussed. First, you take a BS on a rod held on a point of known elevation (KE). Then add the BS reading to the known elevation to determine the HI. Next, take an FS on a rod held at the point of unknown elevation (UKE). Finally, subtract the FS reading from the HI to establish the elevation of the new point.

After you complete the FS, leave the rod on that point and move the instrument forward. Set up the instrument approximately MIDWAY between the old and new rod positions. The new sighting on the back rod becomes a BS, and you can now establish a new HI. The points other than the BMs or TBMs on which you hold the rods for the BSs and FSs are called TURNING POINTS (TPs). Other FSs made to points not along the main route are known as SIDESHOTS. You can use this procedure as many times as necessary to transfer a point of known elevation to another distant point of unknown elevation.

Figure 14-14 shows a sample differential leveling run. The rod is held on BM 35 (Elev. = 133.163). The level is set up midway between BM 35 and

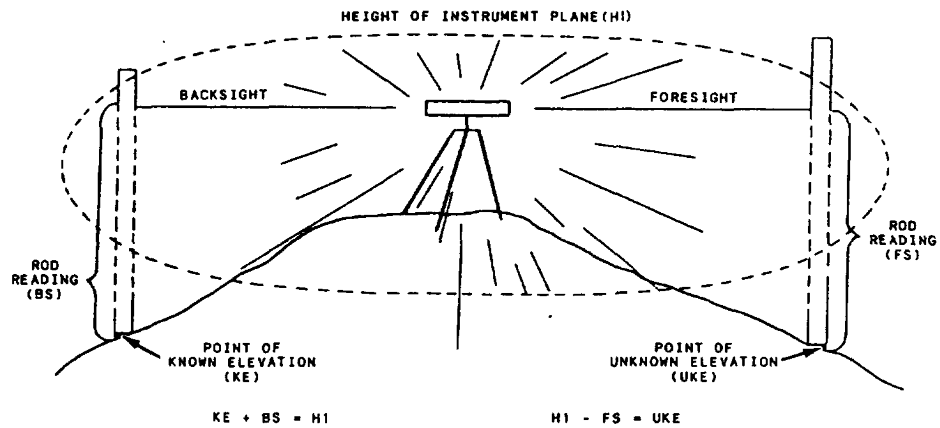
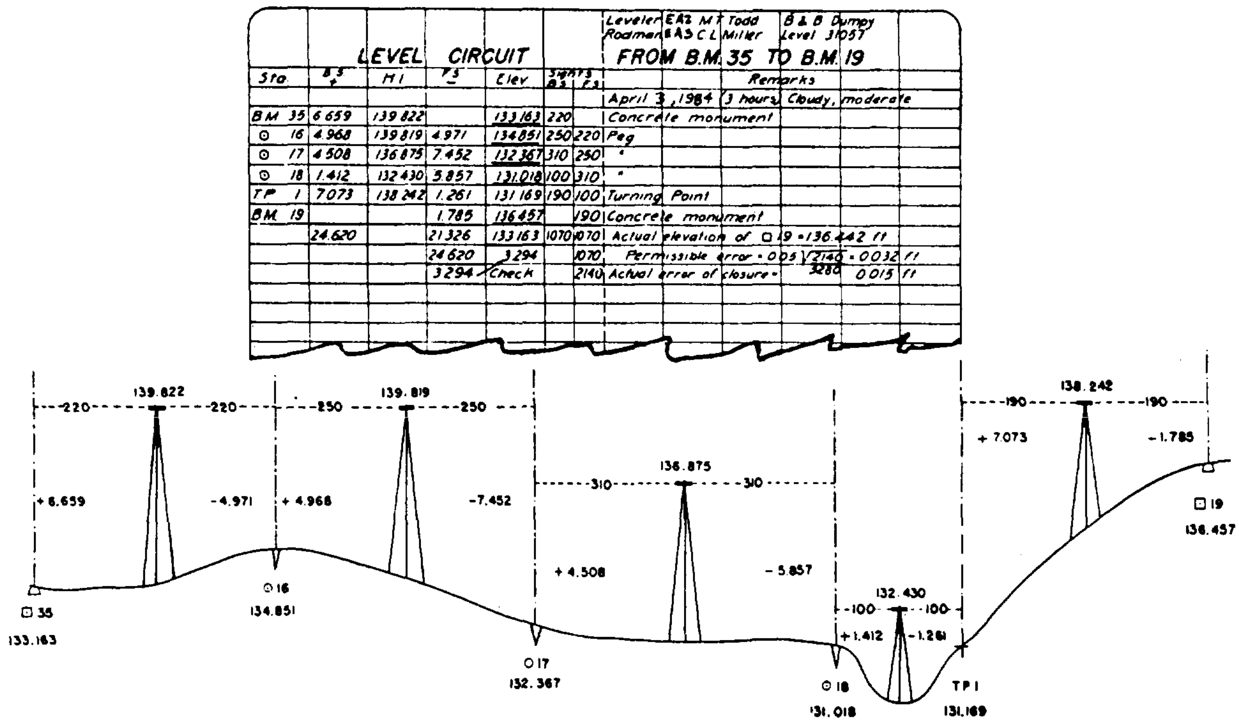


Figure 14-13.-Differersthd leveling.



	LEVEL	CIRCUIT					Leveler EA2 M T Todd Rodman EA3 C L Miller FROM B.M. 35 TO B.M. 19	B & B Dumpy Level 31057
Sta.	BS +	HI	FS −	Elev	Sights BS	Sights FS	Remarks	
							April 3, 1984 (3 hours) Cloudy, moderate	
BM 35	6.659	139.822		133.163	220		Concrete monument	
⊙ 16	4.968	139.819	4.971	134.851	250	220	Peg	
⊙ 17	4.508	136.875	7.452	132.367	310	250	"	
⊙ 18	1.412	132.430	5.857	131.018	100	310	"	
TP 1	7.073	138.242	1.261	131.169	190	100	Turning Point	
BM 19			1.785	136.457		190	Concrete monument	
	24.620		21.326	133.163	1070	1070	Actual elevation of □ 19 = 136.442 ft	
			24.620	3.294		1070	Permissible error = 0.05 $\sqrt{\frac{2140}{3280}}$ = 0.032 ft	
			3.294	Check		2140	Actual error of closure = 0.015 ft	

Figure 14-14—Sample field notes and profile of a differential-level circuit.

TBM 16. The BS reading of +6.659 is added to the elevation of BM 35 and gives the resulting HI (139.822). The rod is moved to Peg 16 (which later becomes TBM 16). The FS reading of –4.971 is subtracted from the HI to get the elevation of Peg 16. Note that the distance (220 ft each way) is also recorded for balancing. The process continues until BM 19 is reached.

LEVEL COMPUTATIONS.— In making level computations, you should be sure to check on the notes for a level run by verifying the beginning BM; that is, by determining that you used the correct BM and recorded its correct elevation, as required.

Then, you should check on the arithmetical accuracy with which you added BSs and subtracted FSs. The difference between the sum of the BSs taken on BMs or TPs and the sum of the FSs taken on BMs or TPs should equal the difference in elevation between the initial BM or TP and the final BM or TP.

Balanced BS and FS distances are shown in figure 14-14. The distance used for the first instrument setup was 220 ft. The first BS (rod reading on ⊡ 35) was 6,659 ft. The first FS (rod reading on ⊙ 16) was 4.971. Notice that the plus sign (+) appears at the top of the BS column and that the minus sign (–) appears at the top of the FS column in the field notebook. This helps you to remember that BSs are added and FSs are subtracted as you compute the new elevations.

The BS taken on a point added to the elevation of the point gives the HI. This establishes the elevation of the line of sight so that an FS can then be taken on any point (BM, TBM, or TP). The level line is extended as far as desired with as many instrument setups as may be necessary by a repetition of the process used in the first setup.

The elevation of ⊡ 35 is 133.163 ft. The first HI is

$$133.163 + 6{,}659 = 139.822 \text{ ft.}$$

The FS subtracted from the HI,

$$139.822 - 4.971 = 134.851 \text{ ft,}$$

gives the elevation of ⊙ 16, the first established. Following through with a similar computation for each setup, notice that the elevation of ⊡ 19 was found to be 136.457 ft.

Look now at the notes in figure 14-14. The sum of all the BSs is 24.620 ft. The sum of all the FSs is 21.326 ft. The difference between the sum of the BSs and the sum of the FSs is

$$24.620 - 21.326 = 3.294 \text{ ft.}$$

This difference should agree with the difference between the actual elevation of BM 35 and the elevation already found for BM 19; that is,

$$136.457 - 133.163 = 3.294 \text{ ft.}$$

This provides a check on the step-by-step computation of elevations.

ADJUSTMENT OF INTERMEDIATE BENCH MARK ELEVATIONS.— Level lines that begin and end on points that have fixed elevations, such as BMs, are often called level circuits. When leveling is accomplished between two previously established BMs or over a loop that closes back on the starting point, the elevation determined for the final BM will seldom be equal to its previously established elevation. The difference between these two elevations for the same BM is known as the ERROR OF CLOSURE. The Remarks column of figure 14-14 indicates that the actual elevation of BM 19 is known to be 136.442 ft. The elevation found through differential leveling was 136.457 ft. The error of closure of the level circuit is

$$136.457 - 136.442 = 0.015 \text{ ft.}$$

It is assumed that errors have occurred progressively along the line over which the leveling was done so that adjustments for these errors are distributed proportionally along the line as shown by the following example: Referring to figure 14-14, you will notice that the total distance between BM 35 and BM 19, over which the line of levels was run, was 2,140 ft. The elevation on the closing BM 19 was found to be 0.015 ft greater than its known elevation. You must therefore adjust the elevations found for the intermediate TBMs 16, 17, and 18.

The amount of correction is calculated as follows:

$$\text{Correction} = \begin{array}{c}\text{Error}\\ \text{of}\\ \text{closure}\end{array} \left[\frac{\text{distance between the starting BM and the intermediate BM}}{\text{distance between the starting and closing BM}} \right]$$

TBM 16 is 440 ft from the starting BM. The total length distance between the starting and closing BMs is 2,140 ft. The error of closure is 0.015 ft.

$$\text{Correction} = -0.015 \times \frac{440}{2140} = -0.003 \text{ ft}$$

The adjusted elevation of TBM 16 is

134.851-0.003 = 134.848 ft.

The adjustments for intermediate TBMs 17 and 18 are made in a similar manner.

Reciprocal Leveling

This procedure is used for either differential or trigonometric leveling when along sight across a wide river, ravine, or similar obstacle must be made. This long sight will be affected by curvature and refraction and by any small error in aligning the line of sight with the bubble axis. The alignment error can be minimized by balancing the long sight and computing the curvature. The atmospheric conditions will vary so much over an open expanse that the refraction correction will be quite erratic. Reciprocal leveling is desired to minimize the effect of the atmosphere as well as the line of sight and curvature corrections. To do this, take the following actions:

1. In reciprocal leveling, balance the BSs and FSs as carefully as possible before you reach the obstacle. In figure 14-15, a TP, N, is selected close to the edge of the obstruction so that it is visible from a proposed instrument location, B, on the other side. A second rod is held on the other side of the obstruction at F. Point F should be selected so that the equivalent distances, AN and FB, and AF and NB, are almost equal. The instrument is setup at point A and leveled carefully. A BS reading is taken on the N rod and an FS on the F rod. These readings are repeated several times. The instrument is moved to point B, set up, and carefully leveled. The rods remain at their stations. Again, a BS is taken on the N rod and an FS on the F rod, and repeated several times. Since instrument leveling is especially critical on reciprocal leveling, you need to check the bubble before each reading and center it carefully. If it is off-center a slight amount, the procedure must be repeated. The difference in elevation between N and F is computed from the readings at A setup and from the readings at B setup separately. Because of the errors in the long sight, the two results will have slightly different values. Note, however, that the long sight is an FS from A and a BS from B. The true difference in elevation is the average of both values, since the errors have opposite signs and will cancel each other.

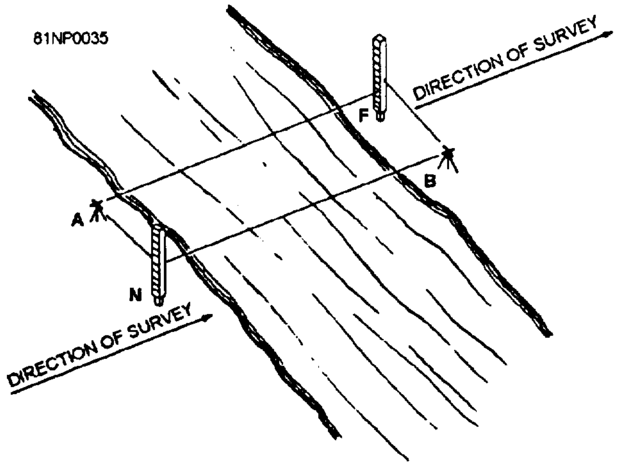


Figure 14-15.-Reciprocal leveling.

2. For more accuracy, make several long sight readings for each short sight and average them. You should use a target on the rod and reset it for each reading. Average each series of long sights and combine this average with corresponding short sights for the computations.

3. Changes in atmospheric density and temperature affect the refraction of a line of sight. The longer the time interval is between reciprocal long sights, the greater the chance of an atmospheric change and a variation in the refraction value. For this reason, you should keep the time lapse between the long sights as short as possible.

4. An excellent method of avoiding the time lapse problem is simultaneous-reciprocal observation. The object is to read both long sight values at the same time. This requires two instruments and two observers and two rods and two rodmen. Some method of communication or sequence of operations must be agreed upon.

5. The note keeping for reciprocal leveling is identical to differential leveling. Take a series of either BS or FS readings on the far rod from one setup and take only one sighting on the rear rod. Average the series of readings, and use a single value to make the elevation computations.

Profile Leveling

In surveying, a PROFILE is a vertical section of the earth measured along a predetermined or fixed line. In practice, profiles are a series of ground elevations determined by differential leveling or other methods that, when plotted along

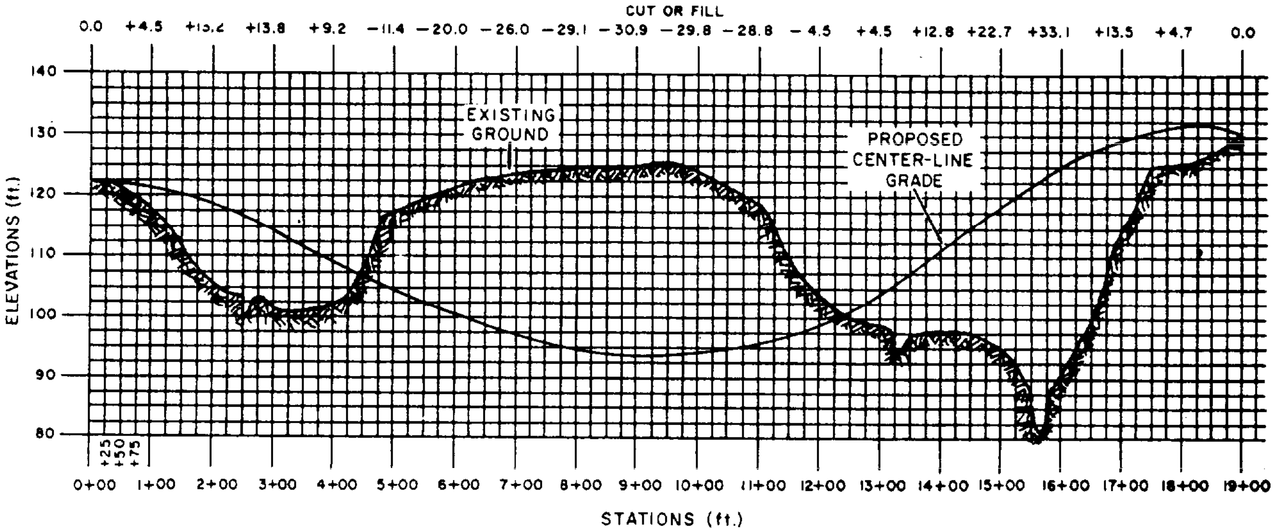


Figure 14-16.-Plotted profile and grade lines along a proposed road center line.

PROFILE LEVELS

Sta.	B+S	H.I.	FS	IFS	Elev.
BM1	7.42	124.93			117.51
0+00				2.4	122.53
1+00(TP1)	0.92	118.45	7.40		117.53
2+00(TP2)	1.42	107.34	12.53		105.92
3+00				4.8	102.54
4+00(TP3)	12.78	115.34	4.78		102.56
4+75(TP4)	12.02	127.21	0.15		115.19
5+00				9.6	117.61
6+00				5.8	121.41
7+00				3.9	123.31
8+00(TP5)	5.07	129.44	2.84		124.37
9+00				4.1	125.34
10+00				4.5	124.94
	34.63		27.70		
−	27.70				
	11.93	TP5 =	124.37		
−	5.07	BM1 =	117.51		
	6.86		6.86		
		CHK.			

0+00 to 10+00	4 JAN 19__
Cloudy & Cold	⊼ SMITH, J., EA 2
Dumpy Level #1	ϕ JONES, R. EA 2
Phila. Rod #1	
National Geodetic Survey Monument,	Bradley, Mo.
Hub driven flush with	existing grade
" " " "	" "
" "	
" " " "	" "
" " " "	" "

Figure 14-17.-Field notes for profile levels shown in figure 14-7.

some line, such as the center line of a road, can be used to determine the final grade or alignment of that road, railroad, or sewer line. Profiles are also used to compute volumes of earthwork.

Figure 14-16 shows a plotted profile of the existing ground surface along a proposed highway center line. Horizontally on the graph, you read a succession of 100-ft stations, from 0 + 00 to 19 + 00. Vertically, you read elevations. Note that, horizontally, the interval between adjacent vertical grid lines represents 25 ft; but vertically the interval between adjacent horizontal grid lines represents 2.5 ft.

The profile was plotted through a succession of points, each of which was obtained from a profile elevation taken on the ground. Figure 14-17 shows field notes for the levels taken from 0 + 00 through 10 + 00. The level was first set up at a point about equidistant from station 0 + 00 and from a BM identified as National Geodetic Survey Monument, Bradley, Missouri. The elevation of the BM was 117.51 ft. The first backsight reading on a rod held on the BM was 7.42 ft. The height of instrument (HI) was therefore

117.51 + 7.42 = 124.93 ft.

You can see this entered in the "HI" column.

From the first instrument setup, FSs were taken on station 0 + 00 and 1 + 00. The elevation of the station in each case was determined by subtracting the FS reading from the HI. Note that the FS taken on station 1 + 00 is entered in a column headed "FS, " while the one taken on station 0 + 00 is entered in a different column, headed "IFS." "IFS" means intermediate FS, or an FS taken on a point that is neither a BM nor a TP, You can see that station 1 + 00 was used as a TP in shifting the instrument ahead. Only FSS taken on BMs or TPs are entered in the column headed "FS."

After an FS was taken on station 1 + 00, it became necessary to shift the instrument ahead. Station 1 + 00 was used as the TP. From the new instrument setup, a BS was taken on a rod held on 1 + 00. The new HI was found by adding the BS reading to the previously determined elevation of 1 + 00.

From the new setup, an FS was taken on station 2 + 00; again, the elevation was found by subtracting the FS reading from the HI. After this sight was taken, the instrument was again shifted ahead, probably because of the steepness of the slope. This time, station 2 + 00 was used as the TP_2. From the new setup, a BS was taken on station 2 + 00 and a new HI established. From this setup, it was possible to take FSs on both station 3 + 00 and station 4 + 00. Because station 3 + 00 was not used as a TP, the FS on it was entered under IFS.

Apparently, the slope between station 4 + 00 and station 5 + 00 was so steep that sighting both stations from the same setup with the rod being used was impossible. Consequently, an intermediate TP (TP_4) was established at station 4 + 75 by determining the elevation of this station. The instrument was shifted to a setup from which a BS could be obtained on a rod held on this station and from which FSs on stations 5 + 00, 6 + 00, 7 + 00, and 8 + 00 could be taken, Station 8 + 00 was then used as a TP for the last shift ahead. From this last setup, it was possible to take FSs on stations 9 + 00 and 10 + 00.

As a check on the arithmetic, you customarily check each page of level notes to check the difference between the sum of the FSs and the sum of the BSs against the difference in elevation between the initial BM or TP and final BM or TP. Obviously, only the BSs and FSs taken on BMs and TPs are relevant to this check, This is the reason why intermediate FSS not taken on BMs or TPs are entered in a separate column.

If the arithmetic is correct, the two differences will be the same. As you can see, the sum of the relevant BSs in figure 14-17 is 39.63; the sum of the FSs is 27.70; and the difference between the two is 11.93. Note that from this difference, the BS taken on TP_5 is deducted. The reason is the fact that this BS is not offset by a corresponding FS on a BM or TP. With the BS taken on TP_5 deducted, the difference between the sum of the FSs and the sum of the BSs is 6.86. The difference between the elevation of TP_5 and the elevation of the initial BM is 6.86, so the arithmetic checks.

Remember that this procedure provides a check on the arithmetic only. If you have recorded any incorrect values, the arithmetic will check out just as well as when you have recorded the correct values. The procedure is valuable, however, for detecting two mistakes commonly made by beginners. These are subtracting a BS from, instead of adding it to, a BM elevation to get the HI; and adding an FS to, instead of subtracting it from, the HI to get an elevation.

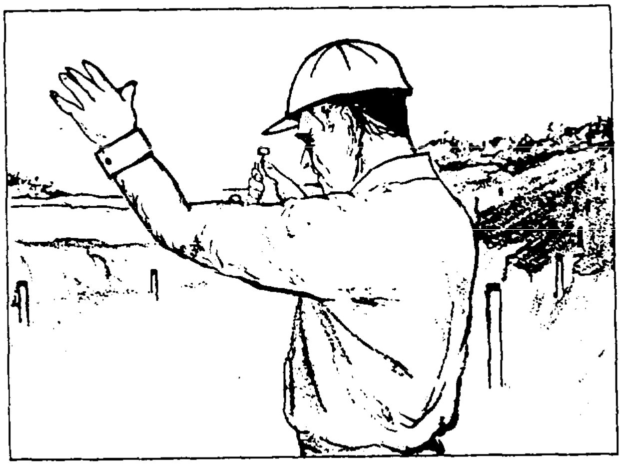


Figure 14-18.—Using angle prism for sighting 90° from the center-line stakes.

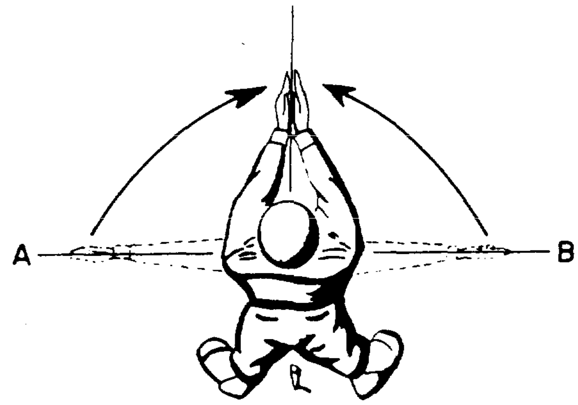


Figure 14-19.-Laying off a 90° angle from the center-line stakes.

Cross-Section Leveling

In profile leveling, you determine the elevations of a series of points lengthwise along a highway. In cross-section leveling, you determine the elevations of points on a succession of lines running at right angles to the lengthwise line of the highway. The principal purpose of profile leveling is to provide data from which the depth of fill or cut required to bring the existing surface up to, or down to, the grade elevation required for the highway can be determined.

Note that profile leveling provides this data relative to the center line. In figure 14-16, you can see along the top the depth of cut or fill required at each station to bring the existing surface to grade—the prescribed grade line for the highway is indicated by the smoothly curved grade line shown. At each station, you can determine the cut or fill by counting the squares between the profile and the grade line.

The cross-section lines are established at regular stations, at any plus stations, and at intermediate breaks in the ground. Short cross-lines are laid out by eye, but long crosslines are laid out at a 90° angle to the center line with the transit. For short crosslines, most surveyors prefer to use an angle prism for sighting 90° angles from the center line. Figure 14-18 shows a surveyor using an angle prism for sighting a 90° angle from the center line of the highway.

For cross-section leveling, strip topography, and some other purposes, it is necessary to lay off a 90° angle at numerous points along a line. This 90° angle can often be established by estimation with sufficient accuracy for the particular job. The surveyor straddles the point on the line, arms extended sideward along the marked line (fig. 14- 19). By looking alternately right then left, he adjusts the position of his feet until his body is in line with AB. He then brings his hands together in front of him, thus pointing along an approximate 90° line from the marked line. An experienced surveyor can lay off a 90° angle by this method so that a point 100 ft away will be within 1 ft of the true perpendicular.

You should measure all elevations at abrupt changes or breaks in the ground with a rod and level. Measure all distances from the center line with a metallic tape. In rough country, the hand level can be used to advantage for obtaining cross sections if the center-line elevations have been determined by use of the engineer's level.

Cross-section leveling is usually done with a hand level after the profile run has been made. The method is as follows:

From the profile run, you know the center-line elevation at each station. Suppose you want to take cross-section elevations at 10 ft intervals for 40 ft on either side of the center line. The first thing you do is to determine the vertical distance from the ground to your line of sight through the hand level when you stand erect with the level at your eye. The best way to do this is to sight on a level rod held plumb in front of you. Suppose you find that the vertical distance is 5.5 ft. Then your HI at any center-line station is the center-line elevation (obtained in the profile level run) plus 5.5 ft.

Suppose that you are standing at station 0 + 00, figure 14-16. The elevation of this station is 122.53 ft. Your HI is therefore

.122.53 + 5.5 = 128.03 ft.

You round off cross-section elevations to the nearest 0.1 ft. If a rodman holds a rod 40 ft to the left of the center line at station 0 + 00 and you read 1.9 ft on the rod, then the elevation of the point plumbed by the rod is

128.0 – 1.9 = 126.1 ft.

The rodman now moves on to a point 30 ft from the center line. If you read 3.3 ft on the rod, the elevation of this point is

128.0 – 3.3 = 124.7 ft.

Going on in this manner, you determine the elevations at all the required points on the cross section. You then move to the next station and repeat the process.

Cross section notes are recorded in the field book by using one of two basic methods. In the first, and often preferred, method, begin at the bottom of the page and read upward, as shown in figure 14-20. This method helps to keep you oriented in the direction in which the line runs and helps to prevent confusion as to which is the right or left side of the line. It therefore reduces the possibility of recording your readings on the wrong side of the center line.

In the second method, the notes are recorded in the conventional manner of reading from top to bottom of the page. Whichever method you use, you must remember that as you stand facing the direction in which the line runs, left

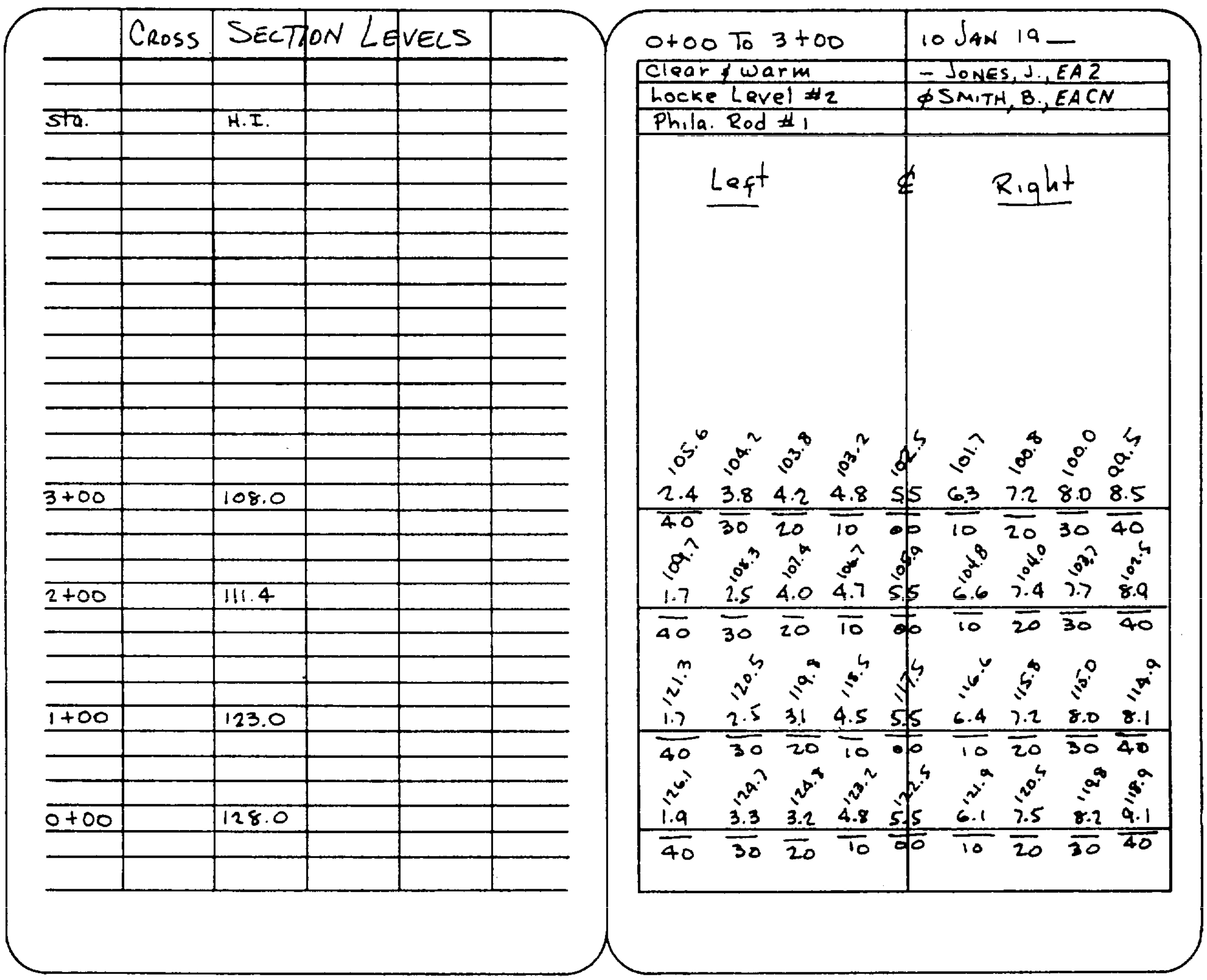


Figure 14-20.-Sample field notes from cross-section leveling at first three stations shown in figure 14-7.

and right in the notebook must correspond to left and right in the field.

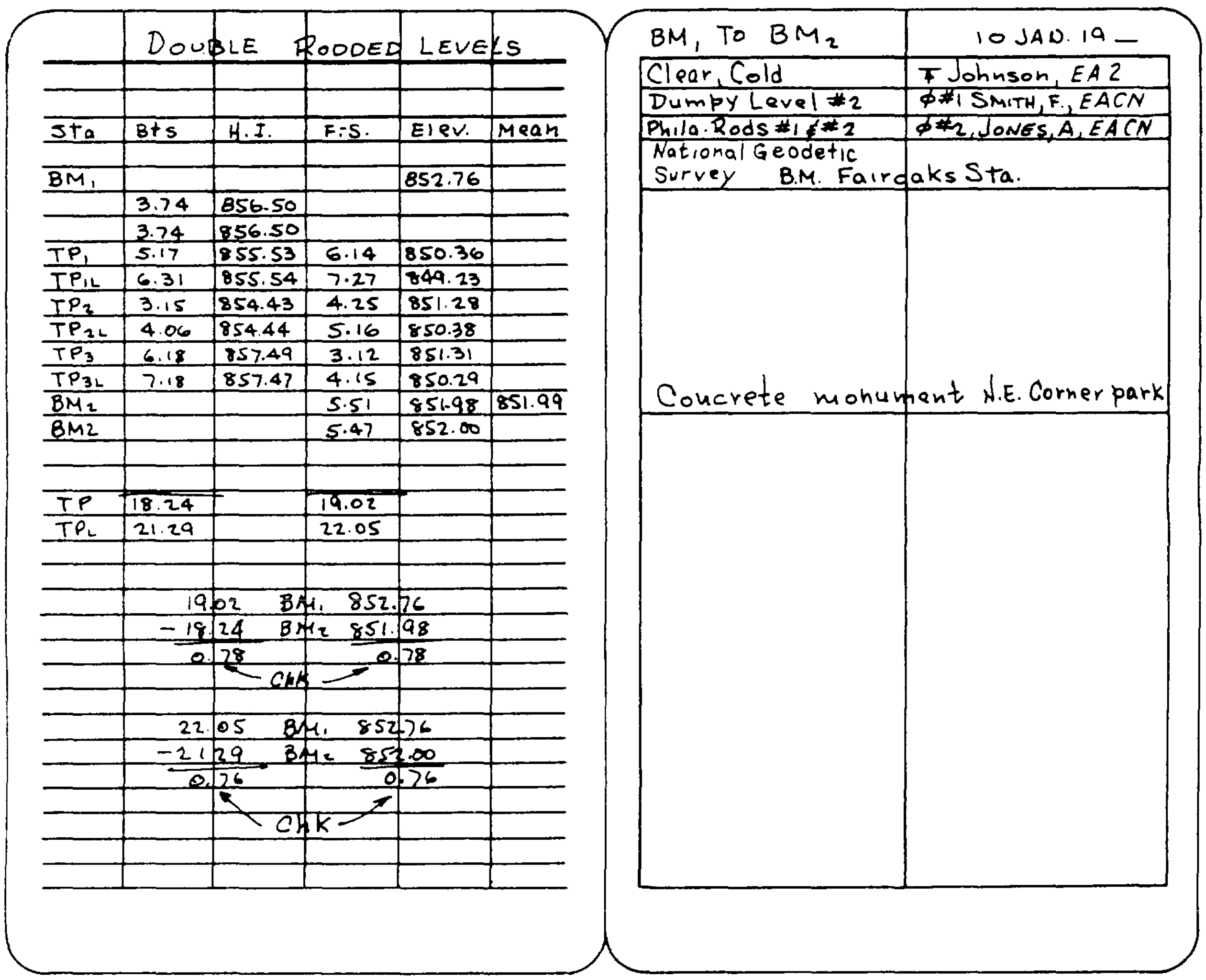
Figure 14-20 shows field notes for cross-section levels taken on the first three stations shown in figures 14-16 and 14-17. On the data side, only the station and the HI need to be listed. On the remarks side, each entry consists of a point elevation, written over the distance of the point from the center line. The computed elevation, determined by subtracting the rod reading from the HI, is written in above as shown. Note that the rod reading at the center line is the 5.5-ft vertical distance from your line of sight to the ground. Also, notice that the center-line elevation written in at each station. is the one obtained in the profile level run. You obtain the HI for each station by simply adding together these two figures.

Double Rodding

Double rodding is a form of differential leveling in which a continuous check is maintained on the accuracy of the leveling procedure. It is called double rodding because it can be done most conveniently by two rodmen. However, it is possible to carry out the procedure using only one rodman.

In double rodding, you determine the HI at each setup point by backlights taken on two different TPs. If no mistake or large error has been made, the result will be two HIs that differ slightly from each other. Elevations computed this way will also differ slightly. In each case, the average is taken as the elevation.

Figure 14-21 shows double-rodded level notes for a run from one BM to another by way of three



DOUBLE RODDED LEVELS

Sta	Bts	H.I.	F.S.	Elev.	Mean
BM1				852.76	
	3.74	856.50			
	3.74	856.50			
TP1	5.17	855.53	6.14	850.36	
TP1L	6.31	855.54	7.27	849.23	
TP2	3.15	854.43	4.25	851.28	
TP2L	4.06	854.44	5.16	850.38	
TP3	6.18	857.49	3.12	851.31	
TP3L	7.18	857.47	4.15	850.29	
BM2			5.51	851.98	851.99
BM2			5.47	852.00	
TP	18.24		19.02		
TPL	21.29		22.05		

19.02 BM1 852.76
− 18.24 BM2 851.98
0.78 0.78
CHK

22.05 BM1 852.76
− 21.29 BM2 852.00
0.76 0.76
CHK

BM1 TO BM2	10 JAN. 19__
Clear, Cold	⊤ Johnson, EA 2
Dumpy Level #2	ϕ#1 SMITH, F., EACN
Phila. Rods #1 & #2	ϕ#2, JONES, A., EACN
National Geodetic Survey B.M. Fairoaks Sta.	
Concrete monument N.E. Corner park	

Figure 14-21.-Sample field notes from double-rodded levels.

intermediate TPs. In each case, a “higher” TP (as TP_1) and a “lower” TP (as TP was used, resulting in two different HIs for each. Computed by way of the higher HIs, the elevation of BM_2 came to 851.98 ft. Computed by way of the lower HIs, it came to 852.00 ft. The mean (average) of 851.99 ft was taken as the correct elevation.

INDIRECT LEVELING

Indirect methods of leveling encompass both trigonometric and barometric leveling. TRIGONOMETRIC LEVELING uses vertical angles and a horizontal distance to compute the difference in elevation, BAROMETRIC LEVELING uses the difference in atmospheric pressures that are observed by a barometer or an altimeter to determine the elevation differences. Indirect methods of leveling will be discussed at the EA2 level.

PRECISION IN LEVELING; MISTAKES AND ERRORS IN LEVELING

Leveling, like any other surveying operation, is carried out by following a prescribed ORDER OF PRECISION—meaning that the instruments you use and the methods you follow have to be those that can give you the specified standard of accuracy.

PRECISION IN LEVELING

FIRST-ORDER leveling is used to establish the main level network for an area and to provide basic vertical control for the extension of level networks of the same, or lower, accuracy in support of mapping projects, cadastral (recording property boundaries, subdivision lines, buildings, etc.), and local surveys. Level lines must start and end on proven, existing BMs of the same order. New levels must be run between the starting BM being used and at least one other existing BM and must show there is no change in their relative elevations.

SECOND-ORDER leveling is used to subdivide nets of first-order leveling and to provide basic control for the extension of levels of the same, or lower, accuracy in support of mapping projects and local surveys. Second-order levels are divided into two classes: Class I and Class II. CLASS I is used in remote areas where the line must be longer than 25 mi because routes are unavailable for the development of additional or higher order networks and for spur lines. CLASS II levels are used for the development of nets in the more accessible areas. In Class I leveling, it is required that all lines start and close on previously established BMs of first or second order. New levels have to be run between the existing BM being used and at least one other existing BM to prove that they have not changed their relative elevations. The criteria for Class II are the same as for Class 1, except that Class II lines are run in one direction only.

THIRD-ORDER leveling is used to subdivide an area surrounded by first- and second-order leveling and to provide elevations for the immediate control of cadastral, topographic, and construction surveys for permanent structures. The following criteria should be observed in third-order leveling:

1. All lines have to start from, and close on, two previously established BMs of third, or higher, order of accuracy if the new leveling indicates they have not changed in their relative elevations.
2. In the United States, third-order lines should not be extended more than 30 mi from BMs of first or second order. In foreign or remote areas, the distance may be extended according to the evaluation of the existing control and the situation. They may be single-run (one direction) lines but should always be loops or circuits that close upon BMs of an equal or a higher order.
3. When a line from previously established third-order marks is extended, the maximum length of the new line is greatly reduced. The distance and allowable error are to be carried back through the existing line to the nearest tie BM of the second or higher order.
4. Balanced sights should not be greater than 300 ft. BS and FS distances maybe measured by pacing and approximately balanced between BMs, Rod readings are read to thousandths and the rod waved for extended rod readings. The bubble is checked to make sure it is exactly centered before each sighting and reading. Turning point pins or plates or well-defined points on solid objects are used for TPs.

FOURTH-ORDER leveling is used to subdivide an area within a third-order network. This is the method of leveling used in connection “with the location and construction of highways, railroads, and most other engineering works that concern the SEABEEs in advanced base projects.

But, in practice, trying to shoot for a higher degree of accuracy is advantageous if it does not affect the proper progress of the work. The following criteria should be observed in fourth-order leveling:

1. All lines are to start from, and close on, previously established BMs of the third or fourth order of accuracy.

2. Maximum sight distance is about 500 ft. Rod readings are read to hundredths of a foot. BS and FS distances are roughly balanced only when lines of great lengths are run, either uphill or downhill. TPs are taken on solid or any well-defined, firm objects.

The instrument commonly used in third- and fourth-order leveling is the engineer's level and the Philadelphia rod. Always check the proper adjustments of the instrument before using it.

Order of Precision

The precision of a level run is usually prescribed in terms of a maximum error of closure. This is obtained by multiplying a constant factor by the square root of the length of the run in miles or in kilometers, depending upon the system of measurement being used. The Federal Bureau of Surveying and Mapping specifies certain requirements and the maximum closing errors, such as those shown in table 14-1. You may refer to this standard if the order of precision is not specified for a particular survey project.

Calculating Error of Closure

A level run that begins at a particular BM and is carried back again to the same BM is called a level loop. A run that does not close on the initial BM is called a level line. A level line closes on another BM; but when a level line is carried back to its origin, it becomes a level loop. Usually, a level line is carried back to the initial BM to determine the error of closure.

Error of closure is simply the difference between the known elevation of the initial BM and the elevation of the same (BM) as computed in the level run.

The error of closure that can be allowed depends on the precision required (first, second, or third order). The permissible (or allowable) error of closure in accuracy leveling is expressed in terms of a coefficient and the square root of the horizontal length of the actual route over which the leveling was done.

Most differential leveling (plane surveying) is third-order work. In third-order leveling, the closure is usually made on surveys of higher accuracy without doubling back to the old BM at the original starting point of the level circuit. The length of the level circuit, therefore, is the actual distance leveled. For third-order leveling, the allowable error is as follows:

$$0.050\ \text{ft}\sqrt{\text{length of the level circuit in miles}}$$

By adding the sight distances in the sixth and seventh columns of the differential level circuit shown in figure 14-14, you will find that the length of the level circuit is 2,140 ft. The length in miles is

$$2140 + 5280 = 0.405.$$

The allowable error of closure is

$$0.050\sqrt{0.405} = 0.050(0.64) = 0.032\ \text{ft}.$$

Since the actual error is only 0.015 ft, the results are sufficiently accurate.

First- and second-order levels usually close on themselves. The leveling party runs a line of levels from an old BM or station to the new BM or station, and then doubles back to the old BM for closure. The actual distance leveled is twice the length of the level circuit.

For second-order leveling, the allowable error is

$$0.035\ \text{ft}\sqrt{\text{length of the level circuit in miles}}$$

First-order leveling is still more precise. The allowable error cannot be greater than

$$0.017\ \text{ft}\sqrt{\text{length of the level circuit in miles}}$$

MISTAKES AND ERRORS IN LEVELING

As explained in an earlier chapter, the terms *mistakes* and *errors* are NOT synonymous in surveying.

Leveling operations, like other survey measurements, are susceptible to both. Mistakes can be avoided by a well-arranged system of operation and by constant alertness by the survey party members. Checking, as described in some of the operations, will eliminate many possible

Table 14-1.—Leveling Order of Precision

REQUIREMENTS	FIRST ORDER	SECOND ORDER		THIRD ORDER	FOURTH ORDER
		Class 1	Class II		
*Spacing of lines and crosslines ----------------	72 km or 40 miles	40-56 km or 25-35 miles	10 km or 6 miles	Not specified	None
Average spacing of permanently marked BMs along lines, not to exceed ----------------	2 km or 1 mile	2 km or 1 mile	2 km or 1 mile	5 km or 3 mile	None
Length of sections -----	1-2 km or 1/2-1 mile	1-2 km or 1/2-1 mile	1-2 km or 1/2-1 mile	Not specified	None
Check between forward and backward running between fixed elevations or loop closure not to exceed -------------------	$4\text{mm}\sqrt{k}$ or $0.017\text{ ft}\sqrt{M}$	$8.4\text{mm}\sqrt{k}$ or $0.035\text{ ft}\sqrt{M}$	$8.4\text{mm}\sqrt{k}$ or $0.035\text{ ft}\sqrt{M}$	$12\text{mm}\sqrt{k}$ or $0.05\text{ ft}\sqrt{M}$	0.6 m for lines up to 20 km or $0.1\text{ ft}\sqrt{M}$

k = the distance in kilometers.
M = the distance in miles.
*In areas outside the U.S. this criteria may be changed to conform with the situation.

areas of mistakes. Errors cannot be completely eliminated, but they can be minimized so that their effect on the survey accuracy will be small and within the tolerances permitted.

Identifying Leveling Mistakes

The leveling mistakes discussed here are not intended to include all possibilities but will give an idea of the more common ones. The survey party personnel should be aware of these possibilities and should be careful to avoid these mistakes. Some of the common mistakes are as follows:

1. Not setting the rod on the same point for an FS and the following BS. Using a turning pin, pedestal, stake, or marking the location with chalk on hard surfaces will help you to recover the identical point.

2. Neglecting to clamp the target or the rod when extended. Any slippage can pass unnoticed and result in a wrong reading that may require an entire rerun of the line to discover the mistake. The rodman should watch the rod or target for any movement as the clamp is tightened. The rod extension or target should be read again after the clamp has been set.

3. Reading the wrong mark. This is a common mistake. The figures on a rod may be obscured by brush or may fall in a position in the field of view so that the instrumentman cannot see two consecutive numbers. Under these conditions, he may read the wrong mark or even read in the wrong direction. This is a great possibility when an inverting eyepiece is being used. For example, if the figure 2 is the only number visible, the instrumentman might read "up" the rod—2.1, 2.2, 2.3 when actually he should be reading 1.9, 1.8, 1.7. Another possibility is miscounting the number of divisions. There is no way to check or discover these mistakes except to be aware of their possibility and to read carefully.

4. Recording a reading in the wrong column. In leveling, readings are not entered into the notebook in a normal sequence, such as left to right across the page. There is always a chance that one or more values may be recorded in the wrong column. The recorder must be alert to avoid making this mistake.

5. Reading the wrong angle sign in trigonometric leveling. The instrumentman can accidentally call out a wrong sign in reading the angle. This type of mistake can be eliminated by the recorder watching the telescope as a pointing is made on the rod. If the wrong one is called out, both the recorder and the instrumentman can resolve it immediately.

6. Recording the wrong sign. The sign varies depending on whether the rod reading is a BS or an FS, and whether the angle is a depression or an elevation. Also, the difference in elevation computation requires a sign reversal if the angle is read for the BS, but not for the FS. These variations can be confusing; the recorder has to be careful to avoid mistakes. This can be done by recording the angle and rod reading signs as read. The sign conversion, if needed, shows up when you compute the DE. Examining the computations to see if all BS DEs have a sign opposite to the angle sign is simple.

7. Subtracting the BS or adding the FS in differential leveling. If the BS or FS is recorded properly (see Number 4 above), you can discover the mistake when you add the BS column and the FS column for a computation check.

8. Using the wrong horizontal cross hairs. This occurs on an instrument provided with stadia hairs.

Identifying Leveling Errors

Generally, errors cannot be totally eliminated, but they can be contained within acceptable tolerances. This requires you to use the prescribed methods and instruments and apply corrections established either mathematically or by experience. Some of the conditions that produce errors are listed below.

1. Instrument not properly adjusted. A small amount of residual error will always exist in any adjustment. For the more accurate surveys, the residual error can be minimized by using BS and FS balancing and, in trigonometric leveling, by taking direct and reverse (circle left and circle right) readings for the angles.

2. Instrument not leveled properly. Unlike the residual adjustment error that will affect the readings one way consistently, this is a random or accidental error. It may affect the line of sight differently at each setup. This error can be minimized only by careful leveling each time the instrument is set up and by recentering the bubble before each reading.

3. Telescope not focused properly. Misfocusing and parallax in the eyepiece create accidental errors that cannot be corrected. The only way to avoid or minimize this error is to take care to focus properly at each setup. The instrumentman

should check and clear parallax before the first sighting and should not readjust it until all sightings from the setup are complete.

4. Rod improperly plumbed. This error is caused by a rodman who does not pay attention to his work. The instrumentman can call attention to plumbing if it is at a right angle to his line of sight, but he cannot see it in the direction of line of sight. The use of a rod level or waving the rod will avoid this error.

5. Unstable object used for a TP. The rodman causes this error by selecting a poor point of support, such as loose rocks or soft ground. As the rod is turned between sights, the weight of the rod can shift a loose rock or sink into soft ground. The elevation of the TP as used for the next BS can change appreciably from the value that had been computed from the previous FS. This error can be avoided by using the turning pin or pedestal when the ground does not present solid points.

6. Rod length erroneous. This error results in either too long or too short rod readings at each point. In a survey predominately over slopes, this error will accumulate. The rod length should be checked with a steel tape at intervals to locate this error.

7. Unbalanced BS and FS distances. The unbalanced distances do not cause the error. It is caused by the effect on the line of sight from residual adjustment and leveling errors and the effect of curvature and refraction errors. Readings you take at a long distance will have a greater error than those at a short distance. This unbalance may not be critical on one setup but can be compounded into a considerable error if the unbalance continues over several setups. By balancing the sight distances at each instrument setup, if possible, and the sums of the BS and FS distances at every opportunity, you will keep these errors to a minimum.

8. Earth's curvature. This produces an error only on unbalanced sights in leveling. When the BS distances are constantly greater than FS distances, or vice versa, a greater systematic error results, especially when the sights are long. To eliminate this error, you must maintain a balanced sight distance in every BS and FS reading, not just their sum total between BMs (the error varies directly as the square of the distance from the instrument to the rod).

9. Atmospheric refraction. This error also varies as the square of the distance but opposite in sign (+ or –) to that caused by the earth's curvature. The effect of atmospheric refraction is only one-seventh of that caused by the earth's curvature. In first- and second-order leveling, the effect of refraction is minimized by taking the BS and FS readings in quick succession and avoiding readings near the ground. (They should be taken at least 2 ft from the ground.)

10. Variation in temperature. If a portion of the telescope is shaded and some parts are exposed to the sun's rays, it produces some warping effect on the instrument that may affect its line of sight. This effect is negligible in ordinary leveling; but in leveling of higher precision, this effect may produce appreciable error. This is one of the reasons why surveyors use an umbrella to shield the instrument when doing more refined work.

BASIC ENGINEERING SURVEYS AND CONSTRUCTION SITE SAFETY

An engineering survey forms the first of a chain of activities that will ultimately lead to a completed structure of some kind, such as a building, a bridge, or a highway. An engineering survey is usually subdivided into a DESIGN-DATA SURVEY and a CONSTRUCTION SURVEY.

This section discusses the basic engineering surveys commonly performed by an EA survey party in support of military construction activities. In addition, various types of occupational hazards relating to specific surveying operation are also presented in this section together with the precautions or applicable abatement procedures that must be carried out to deter injury to the survey crew and/or damage to surveying equipment or material.

HIGHWAY SURVEYS

Surveys for roads and streets involve both field work and office work. The extent of each type of work depends on the magnitude and complexity of the job. Some phases of the work may be done either in the field or in the office, and the decision as to the exact procedures to be followed will be influenced by the number of personnel available and by the experience and capabilities of the individuals involved.

Design-Data Survey

This type of survey is conducted for the purpose of obtaining information that is essential for planning an engineering project or development and estimating its cost. A typical design-data survey, for example, is a route survey required in the design and construction of a particular road or highway. The initial activities included in a route survey are as follows: reconnaissance survey, preliminary-location survey, and final-location survey.

On the other hand, a long established Navy base might already have well-marked horizontal and vertical control networks and up-to-date topographic maps available. Then perhaps neither a reconnaissance nor a preliminary survey would be required. The road could probably be designed by using the existing design data, and the fieldwork would begin with making the final location survey. In summary, the extent to which data is already available is an important factor in determining what field operations have to be performed.

RECONNAISSANCE SURVEY.— A reconnaissance survey provides data that enables design engineers to study the advantages and disadvantages of a variety of routes and then to determine which routes are feasible. You begin by finding all existing maps that show the area to be reconnoitered. In reconnaissance, studying existing maps is as important as the actual fieldwork. Studying these maps and aerial photographs, if any exist, will often eliminate an unfavorable route from further consideration, thus saving your reconnaissance field party much time and effort.

Contour maps give essential information about the relief of an area. Aerial photographs provide a quick means for preparing valuable sketches and overlays for your field party. Direct aerial observation gives you an overview of an area that speeds up later ground reconnaissance if the region has already been mapped.

Begin the study of a map by marking the limits of the area to be reconnoitered and the specified terminals to be connected by the highway. Note whether or not there are any existing routes. Note ridgelines, water courses, mountain gaps, and similar control features. Look for terrain that will permit moderate grades without too much excavating. Use simplicity in alignment and have a good balance of cuts and fills; or use a profile arrangement that makes it possible to fill depressions with the cut taken from nearby high places.

Mark the routes that seem to fit the needs and that should be reconnoitered in the field. From the map study, determine grades, estimate the amount of clearing required, and locate routes that will keep excavation to a minimum by taking advantage of terrain conditions. Mark stream crossings and marshy areas as possible locations for fords, bridges, or culverts.

Have the reconnaissance field party follow the route or routes marked earlier during the map study. Field reconnaissance provides you with an opportunity for checking the actual conditions on the ground and for noting any discrepancies in the maps or aerial photographs. Make notes of soil conditions, availability of construction materials, such as sand or gravel, unusual grade or alignment problems, and requirements for clearing and grubbing. Take photographs or make sketches of reference points, control points, structure sites, terrain obstacles, landslides, washouts, or any other unusual circumstances.

Your reconnaissance survey party will usually carry lightweight instruments that are not precise. Determine by compass the direction and angles. Determine the approximate elevations by an aneroid barometer or altimeter. Use an Abney hand level (clinometer) to estimate elevations and to project level lines. Other useful items to carry are pocket tapes, binoculars, pedometer and pace tallies, cameras, watches, maps, and field notebooks.

Keep design considerations in mind while running a reconnaissance survey. Remember that future operations may require further expansion of the route system presently being designed. Locate portions of the new route, whenever possible, along roads or trails that already exist. Locate them on stable, easily drained, high-bearing-strength soils. Avoid swamps, marshes, low-bearing-strength soils, sharp curves, and routes requiring large amounts of earthmoving.

Keep the need for bridges and drainage structures to a minimum. When the tactical situation permits, locate roads in forward combat zones where they can be concealed and protected from enemy fire.

The report you turn in for the reconnaissance field party must be as complete as possible; it provides the major data that makes the selection of the most feasible route or routes possible.

PRELIMINARY SURVEY.— A preliminary survey is a more detailed study of one or more routes tentatively selected on the basis of a reconnaissance survey report. It consists essentially of surveying and mapping a strip of land along the center line of a tentatively selected route.

Some of the activities associated with a preliminary survey are as follows: running a traverse (sometimes called a P-line or survey base line), establishing BMs, running profiles, and taking cross sections. For many projects, the preliminary survey may be conducted by a transit-tape party alone. Other projects may require a level party and a topographic party.

Normally, the data gathered from a preliminary survey are plotted while the party is in the field, This practice gives a more accurate representation of the terrain, reduces the possibility of error, and helps to resolve any doubtful situations while you are actually observing the terrain.

FINAL-LOCATION SURVEY.— The final-location survey, usually called the location, constitutes a continuous operation; or, in other words, the survey operation goes on from the start of the project through to the end of the actual construction. The location survey consists of establishing the approved layout in the field, such as providing the alignment, grades, and locations that will guide the construction crew.

The EAs tasked with final-location survey normally start (time and distance) ahead of the construction crew. This is often done to save construction time and to avoid delay of scheduled activities. Some of these activities are setting stakes to mark the limits of final earthmoving operations to locate structures and establishing final grades and alignment.

Before making the final-location survey, you should make office studies consisting of the preparation of a map from preliminary survey data, projection of a tentative alignment and profile, and preliminary estimates of quantities and costs. Use this information as a guide for the final location phase. The final location in the field is carefully established by your transit party, using the paper location prepared from the preliminary survey. The center line may vary from the paper location because of objects or conditions that were not previously considered; but these changes should not be made by you, the surveyor, without the authority of the engineering officer.

Office Work

After the type and general location of a highway are decided and the necessary design data is obtained in the field, a number of office tasks must be performed. These tasks include the following:

1. Plotting the plan view
2. Plotting the profile
3. Plotting the alignment
4. Designing the gradients
5. Plotting the cross sections
6. Determining end areas
7. Computing the volumes of cut and fill

Repeat these operations one or more times as trial designs are developed and then revised or discarded. For a highway plan and profile, plot on the same sheet. Figure 14-22 shows a plotted highway plan and profile view. Plotting cross sections is discussed later in this chapter.

PLOTTING THE PLAN VIEW.— Plotting the plan view of a highway is similar to a traverse except for the introduction of topographic details, curves, and curve data. As a study of highway curves and curve data is beyond the scope of this TRAMAN (but will be studied at the EA2 level), suffice it to say that the important elements of the curve are shown in the form of notes at each curve point. (See the plan view, figure 14-22.)

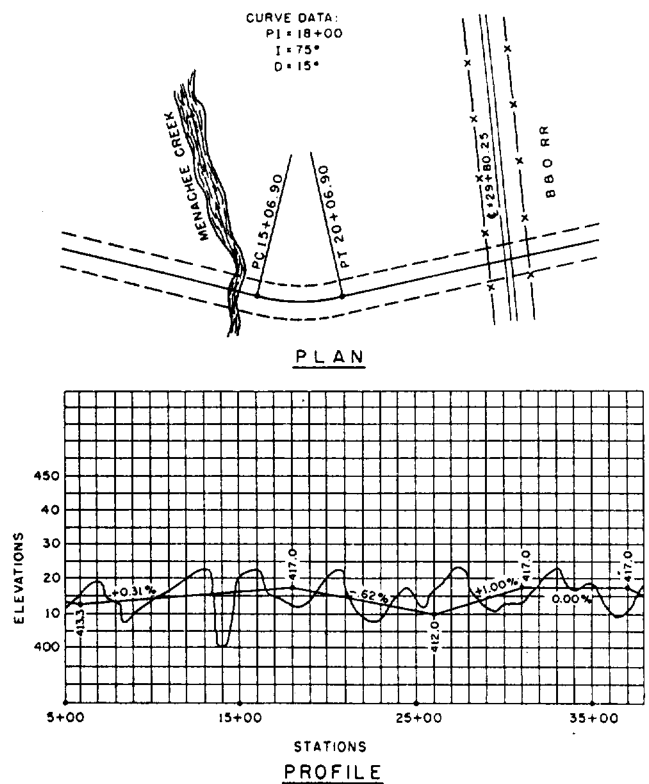


Figure 14-22.-Plan and profile for a highway.

PROFILE PLOTTING.— Make profile plotting on regular profile paper that has ruled horizontal and vertical parallel lines, as shown in figure 14-22. Vertical lines are spaced 1/4 or 1/2 in. apart; horizontal lines are spaced 1/20 or 1/10 in. apart. In figure 14-22, the vertical lines on the original paper (reduced in size for reproduction in this book) were 1/4 in. apart. On the original paper, there was a horizontal line at every 1/20-in. interval; for the sake of clarity, only those at every 1/4-in. interval have been reproduced.

For the first consideration in profile plotting, select suitable horizontal and vertical scales for the profile paper. The suitability of scales varies with the character of the ground and other factors. In figure 14-22, the horizontal scale used was 1 in. = 400 ft, and the vertical scale used was 1 in. = 20 ft (reduced in size for reproduction in this book). Normally, to facilitate the plan plotting, choose scales that are proportional numbers in multiples of ten, such as those given above (H, 1 in. = 400 ft, and V, 1 in. = 20 ft). Write the stations and elevations, as shown in figure 14-22.

Plot the profile, usually from profile level notes, though you may plot it from the elevations obtained from the contour lines. Assume that profile level notes indicate the following centerline elevations at the following stations from 5 + 00 through 15 + 00.

Station	Elevation (feet)
5 + 00	411.9
6 + 00	415.0
7 + 00	417.8
8 + 00	412.0
8 + 75	406.9
9 + 00	411.0
10 + 00	413.2
10 + 50	413.5
11 + 00	415.9
12 + 00	417.3
13 + 00	423.0
13 + 80	412.0
14 + 00	402.0
15 + 00	418.2

As you can see, an elevation was taken at every full station and also at every plus where there was a significant change in elevation. Can you see now how important it is to follow this last procedure? If an elevation had not been taken at 8 + 75, the drop that exists between 8 + 00 and 9 + 00 would not show on the profile.

Check through the listed elevations, and see how each of them was plotted as a point located where a vertical line indicating the station intersected a horizontal line indicating the elevation of that station. Note, too, that usually stations are labeled where the line crosses highways, streams, and railroads.

Besides the profile of the existing terrain, the vertical tangents of the proposed highway center line have been plotted. The end elevation for each of these (that is, the elevations of points of vertical intersection [PVI]) were determined by the design engineers. Various circumstances were considered. One of the important ones was facilitating, as much as possible, the filling of each depression with an approximately equal volume of cut taken from a nearby hump or from two nearby humps.

The gradient, in terms of percentage of slope (total rise or fall in feet per 100 horizontal feet), is marked on each of the vertical tangents. This percentage is computed for a tangent as follows. For the tangent running from station 6 + 00 to station 18 + 00, the total rise is the difference in elevation, or

$$417.0 - 413.3, \text{ or } + 3.7 \text{ ft.}$$

The horizontal distance between the stations is 1,200 ft. The percentage of slope, then, is the value of x in the equation

$$\frac{1200.00}{3.7} = \frac{100}{x} = \text{or } 0.31 \text{ or } 31\%$$

For a tangent running from station 18 + 00 to station 26 + 00, the total slope downward is the difference in elevation, or

$$412.0 - 417.0, \text{ or } -5.0 \text{ ft.}$$

The distance between the stations is 800 ft. The percentage of slope then is the value of x in the equation

$$\frac{800}{-5.0} = \frac{100}{x} = -0.62 \text{ or } -62\%.$$

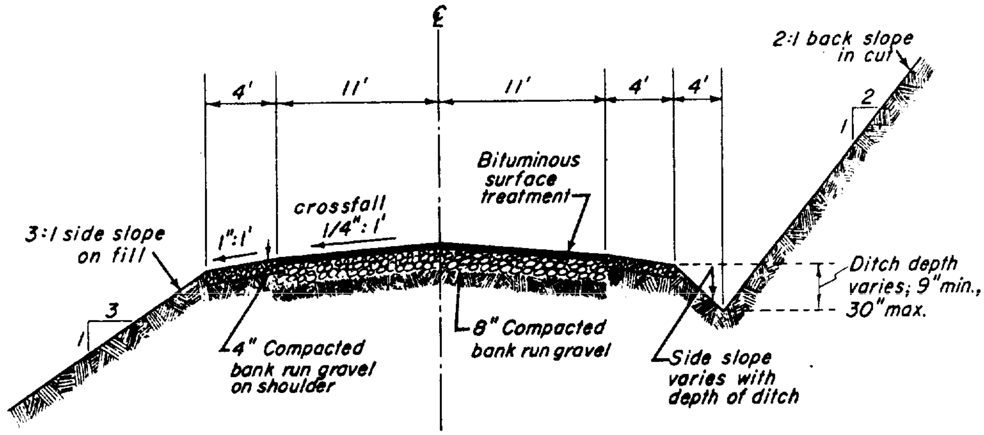


Figure 14-23.-Typical design cross section.

TYPES OF CROSS SECTIONS.— Figure 14-23 shows a typical design cross section, Just about everything you need to know to construct the highway, including the materials to be used and their thicknesses, is given here.

However, this design section is a section of the completed highway. For the purpose of staking out and for earthmoving calculations, the cross-section line of the existing ground at each successive station must be plotted; the design data cross section (typical section of the highway) is then superimposed.

The cross section of the road, with design data available from a previous design-data survey, is staked out by an EA survey party, preferably the leveling crew. Figure 14-24 shows a designed cross section of a 40-ft-wide road taken from a station or point along the road center line. The elevation of the existing surface is 237.4 ft all the way across; therefore, this is called a level section. Finished grade for the highway at this station—that is, the proposed center-line elevation for the finished highway surface—is 220.4 ft. The prescribed side-slope ratio is 1.5:1; that is; a horizontal unit of 1.5 for every unit of vertical rise.

Because the ground line across the cross section is level and the side-slope ratio is the same on both sides, the horizontal distance from the center line to the point where the side slope will meet the natural surface will be the same on both sides. A slope stake is driven at this point to guide the earthmovers. The horizontal distance from the center line to a slope stake can be computed by methods that will be explained later.

In the case of this designed cross section, the data available to you are

1. the width of the highway,

2. the side-slope ratio, and

3. the proposed finished grade.

Besides this, all you need to know to set slope stakes is the ground elevation of the slope-stake point on each side. Because the elevation of the level section in figure 14-24 is the same on both sides, only a single-level shot for elevation is needed. For this reason, a section of this kind is called either a one-level section, or just a level section. Because the entire sectional area consists of material to be excavated or CUT, it is called a section in cut.

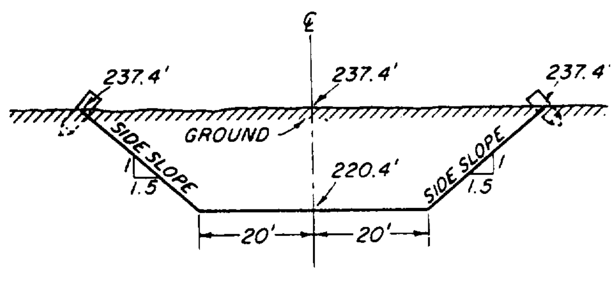


Figure 14-24.-Level section in cut.

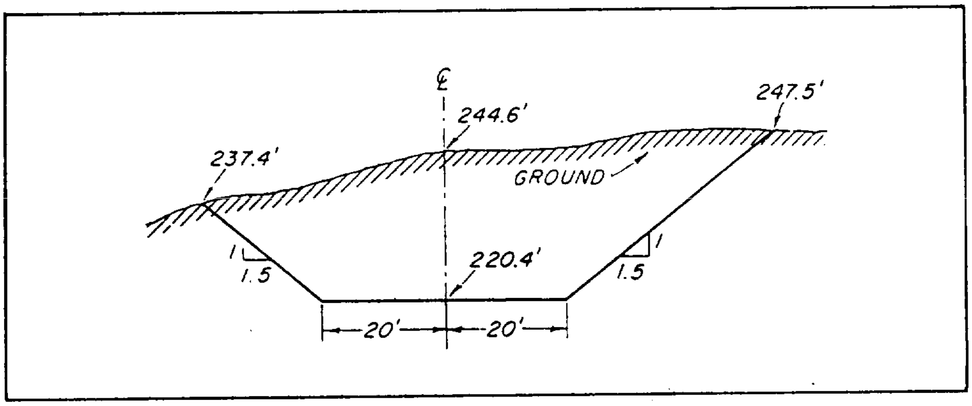


Figure 14-25.-Three-level section in cut.

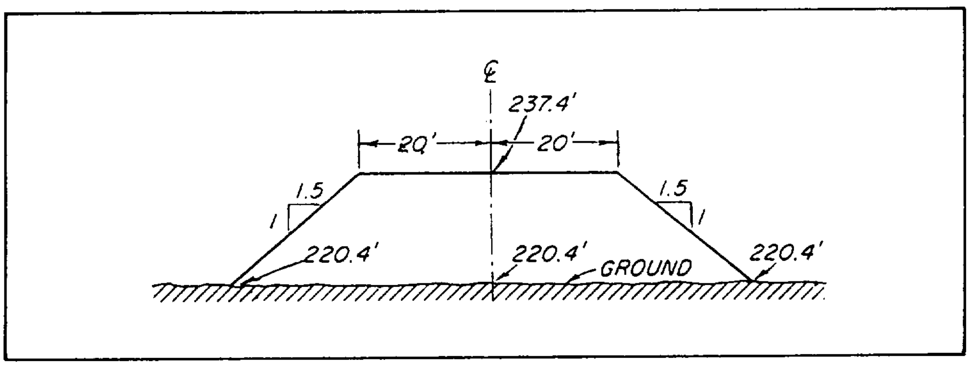


Figure 14-26.-Level section in fill.

In the section shown in figure 14-25, the ground line across the section is sloping rather than level. Therefore, to plot this section, you would need three different elevations: one for the left slope stake, one for the center-line grade stake, and one for the right slope stake. If these three levels are taken, the section is called a three-level section in cut. If additional levels are taken midway between the center line and the slope stake on either side, it is called a five-level section in cut. Therefore, it is a section in cut because the entire cross-sectional area consists of cut.

Level, three-level, and five-level sections are called regular sections.

Figure 14-26 shows a level section in fill; figure 14-27 shows a three-level section in fill. The section shown in figure 14-28 consists of both cut and fill and is called a sidehill section.

When a more accurate picture of cross sections than can be obtained from regular sections is desired, irregular sections are taken and plotted. For an irregular section you take, besides the regular levels, additional levels on either side of the center line. You take these at set intervals and at major breaks in the ground line.

Cross sections may be preliminary or final. Preliminary cross sections, from the P-line or survey base line, are irregular sections that are plotted before the finished grade has been determined. They may be obtained by levels run in the field or by elevations found on the contour lines of a topographic map.

Final cross sections are sections of the final road design. They may be prepared in the same manner as preliminary sections, or they may be regular sections plotted from field data obtained after the finished grade has been set. The term *final cross section* is also applied to as-built sections taken after construction is completed.

PLOTTING CROSS SECTIC)NS.— Cross sections are usually plotted on cross-section paper, which comes either in rolls or sheets. It is ruled into 1-in. squares with heavy, orange or green

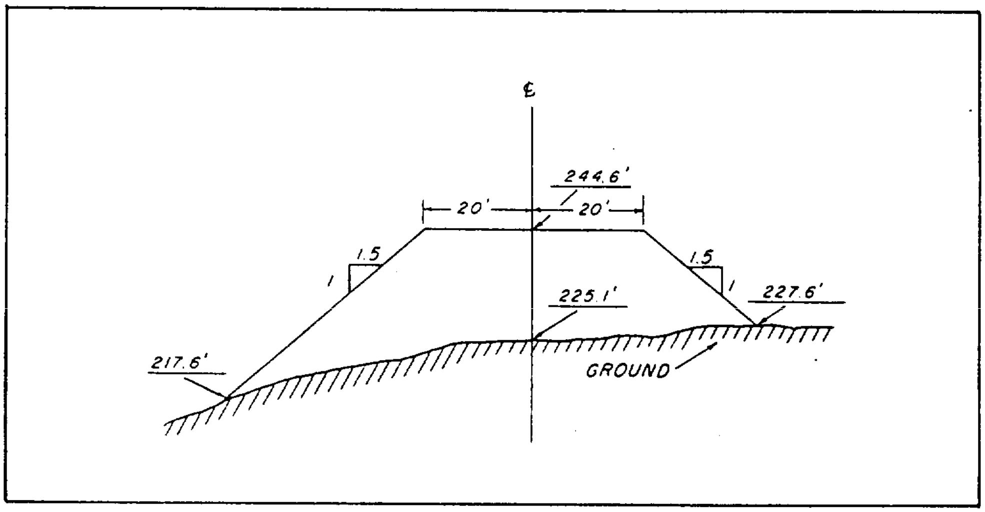


Figure 14-27.-Three-level section in fill.

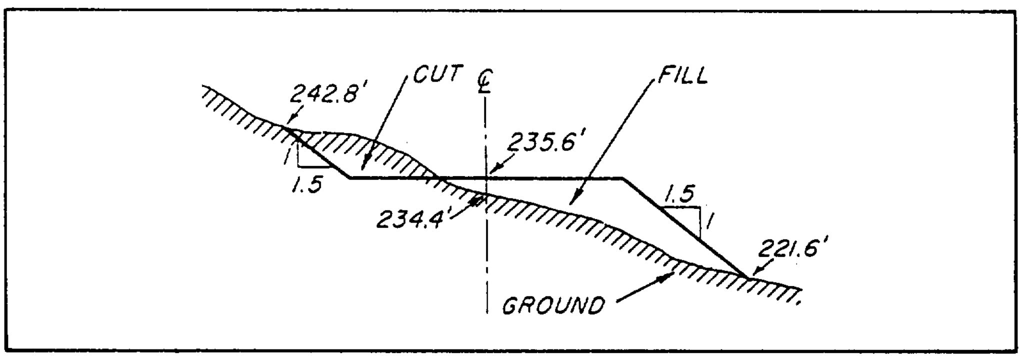


Figure 14-28.-Sidehlll section.

lines and with lighter lines into 1/10-in. squares, Cross-section paper is commonly called 10- x 10-in, paper.

Plot each cross section separately; and below each plot, show the station number. Place the first cross section at the top of a sheet and continue downward until you plot all the sections. Two or more sections may be plotted on the same sheet. In a major highway project, plot cross sections on a continuous roll of cross-section paper. Some surveyors prefer to plot the cross sections from the bottom to the top of the paper. They may also prefer to record cross-section notes in the same manner. If you follow these methods of plotting and recording, you are properly oriented with the actual direction of the highway; that is, your left is also towards the left of the highway; it is also to the left of the cross-section notes and the plotted cross section. Really, it doesn't matter which method you follow as long as you are properly oriented to the direction of the highway at all times.

Unlike profile plotting, in cross-section plotting, the same scale is often used for both the vertical and the horizontal distance. Common scales are 1 in. = 5 ft and 1 in. = 10 ft. When sections are shallow, it is best to exaggerate the vertical scale, making it from two to ten times the horizontal scale.

For the center line for a row of sections, use one of the heavier vertical lines on the paper far enough away from the margin so that no points plotted will run outside the limits of the paper. Note the depths indicated for the first section to be plotted, and select a horizontal line for the base

CROSS-SECTION NOTES
County Road, Ferndale, Mass.
Proj S-52

Sta.	BS	HI	FS	Elev.	
B.M. 3	4.21	76.70	–	72.49	
10+00					
11+00					
+43					Brook Valley
12+00					
T.P. 1	10.84	85.22	2.32	74.38	
13+00					
+67					Summit
14+00					
B.M. 4			6.32	78.90	78.92 Established Elev.

Winslow EA2 ⊼
Rankin EA3
Ludlam CN
Right of Way 80 ft. Oct 30, 19

Sta.	Left			℄	Right		
10+00	40/1.7 (75.0)	25/4.3 (72.4)	10/2.4 (74.3)	3.8 (72.9)	18/4.6 (72.1)	30/5.2 (71.5)	40/8.7 (68.0)
11+00	40/3.3 (73.4)	12/6.8 (69.9)	6/4.2 (72.5)	5.3 (71.4)	15/6.5 (70.2)	28/8.2 (68.5)	40/10.4 (66.5)
+43	40/2.3 (74.4)	28/5.1 (71.5)	16/7.2 (69.5)	9.2 (67.5)		22/10.3 (66.4)	40/11.5 (65.0)
12+00	40/0.4 (76.3)	25/2.7 (74.0)		4.5 (72.2)	8/5.1 (71.6)	20/6.2 (70.5)	40/8.3 (68.4)
13+00	40/3.6 (81.6)	27/4.2 (81.0)	10/8.6 (76.8)	8.3 (76.9)		25/10.2 (75.0)	40/11.9 (73.3)
+67	40/1.2 (84.0)	25/2.6 (82.6)		4.2 (81.0)	10/5.1 (80.1)	16/8.6 (76.6)	40/10.2 (75.0)
14+00	40/2.4 (82.8)	20/3.1 (82.1)	9/4.8 (80.4)	7.6 (77.6)	17/8.2 (77.0)	35/9.1 (76.1)	40/11.3 (73.9)

A CROSS-SECTION NOTES

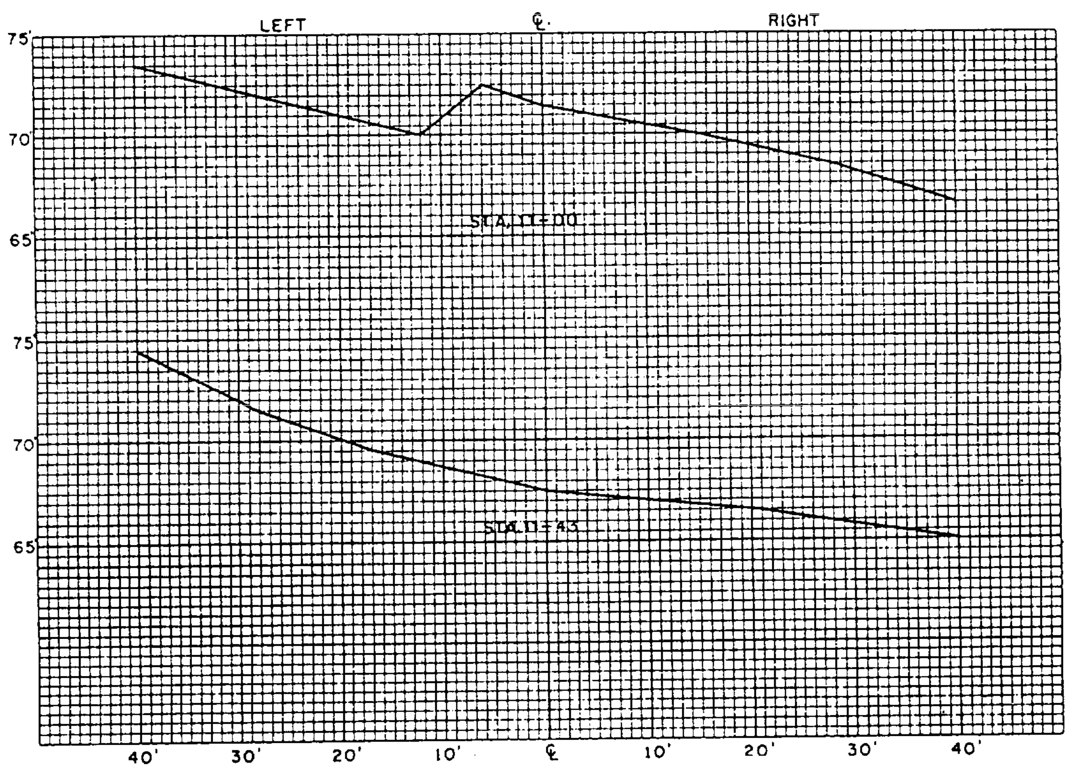


Figure 14-29.-A. Cross section notes. B. Cross sections plotted.

that is about centered between the top and bottom margins. Mark this with the base elevation. Then lay off the horizontal distances of the section surface elevations on either side of the center line, and plot the elevations by using the level data. Finally, connect these plotted points by using a straightedge or by drawing freehand lines.

In figure 14-29, view A, cross-section notes are shown for the existing ground along a proposed road. In figure 14-29, view B, the sections at stations 11 + 00 and 11 + 43 have been plotted. The field party took, for each station, the ground elevation 40 ft to both the right and to the left of the center line. For each station, however, the center-line distance of the intermediate elevations varies. Therefore, these are irregular sections.

For both of the stations plotted, the HI was 76.70 ft. For the point 6 ft left of the center line at station 11 + 00, note the 4.2 written below the 6. This reading was obtained from a rod held on this point. The number 72.5 shown in the parentheses right below the number 4.2 is the elevation of this point. You obtain the elevation by subtracting from the HI, the rod reading FS:

76.70 – 4.20, or 72.50

You can see this point is plotted 6 ft to the left of the center line and at an elevation of 72.5 ft in figure 14-29, view B. Now if the notes are reduced in the office, the general practice is to print the elevations in RED; then the elevation just computed (72.5) will appear in red in the cross-section notes (fig. 14-29, view A).

After the road gradients, either preliminary or final, have been designed, plot the design data cross section on the existing ground line section plot at each station to complete the picture of the end-area as it will be in the finished highway. Obtain the finished grade elevation for each station from the profile. Plot the finished grade point usually located on the center at each cross section. Then draw in the outline of the pavement surface, ditches, and cut or fill slopes as they show on the typical design section. Plotting may be done with triangles, but a faster method is to use templates made of plastic, thin wood, sturdy cardboard, or other suitable material. Prepare templates for a cut section, a fill section, and a sidehill section that may be flipped over to accommodate the direction of hillside slope.

The procedures just described are the most common and pertain to irregular sections. However, if regular sections have been taken in the field after the gradients have been designed, then both the existing and the finished surfaces will be plotted. Field notes for simplified three-level sections on a highway are shown in figure 14-30. On the data side, the profile elevation and the grade elevation at each station are listed. In the columns headed Left and Right on the

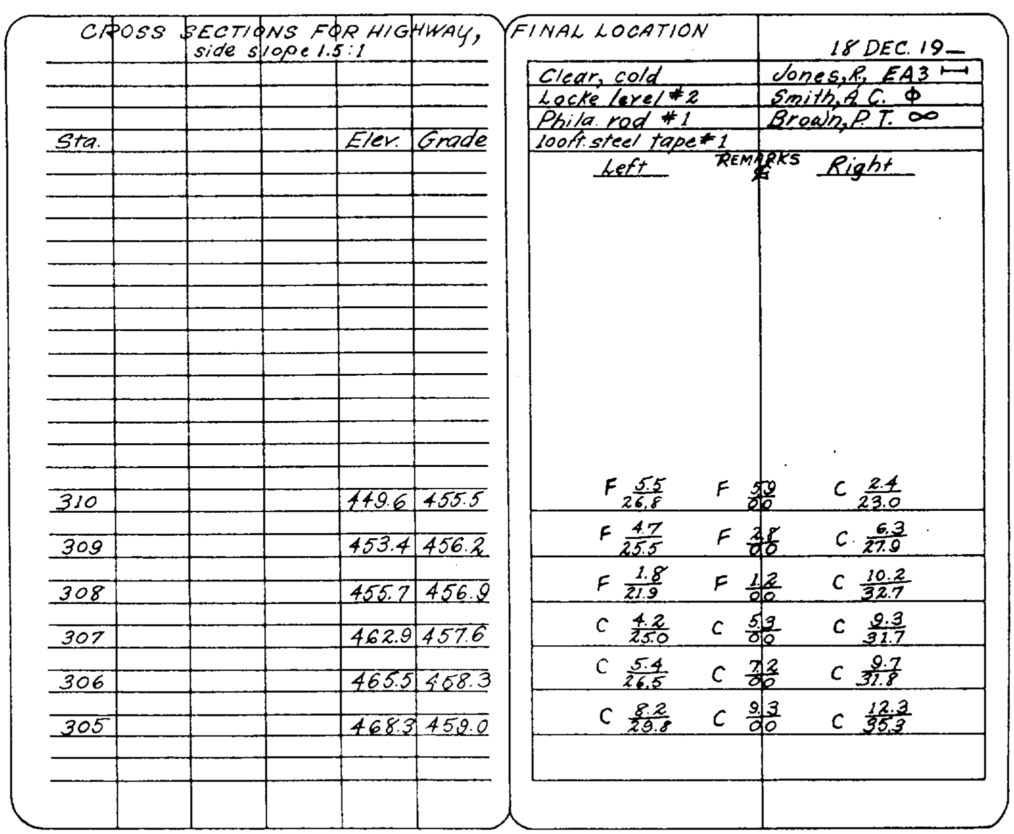


Figure 14-30.-Field notes for three-level cross sections.

remarks side, the upper numbers with the appropriate letter symbols (C for cut, F for fill) are the cuts or fills; the lower numbers are the distances out from the center. These values indicate points at which the slope stakes are driven. If a five-level or irregular section is being recorded, the other points must be written between those for the center and for the slope stakes.

These field notes given you the coordinates that you can use to plot sections, as shown in figure 14-30. In that figure for purposes of clarity, only the lines at every 1/4-in. interval are shown. The scale, both horizontal and vertical, is 1 in. = 10 ft; therefore, the interval between each pair of lines represents 2.5 ft.

The highway is to be 40 ft wide; therefore, the edge of the pavement for each plotted section will be 8 squares (8 x 2.5 = 20) on either side of the center line. Figure 14-30 shows that, for station 305, the left-hand slope stake is located 29.8 ft from the center line and 8.2 ft above grade. The right-hand slope stake is located 35.3 ft from the center line and 12.3 ft above grade. Note how the locations of these stakes can be plotted after you have selected an appropriate horizontal line for the grade line and how the side slopes can then be drawn.

The ground line at the center line is 9.3 feet above grade. Plot a point here, and then finish the plot of the section by drawing lines from the center-line point to the two slope stake points.

Plot a five-level section in exactly the same way, except that you plot in additional ground points between the center line and the slope stakes.

Layout/Stakeout Procedures

The design-data survey is followed by the construction survey that consists broadly of the LAYOUT or STAKEOUT survey and the AS-BUILT survey, which will be discussed later in this chapter. In a layout survey, both horizontal and vertical control points are located and marked (that is, staked out) to guide the construction crews. Figure 14-31 identifies various stakes and hubs used in highway or road construction and their typical arrangement. The functions of the various stakes and hubs are described briefly as follows:

1. CENTER-LINE STAKES indicate the exact center of the roadway construction.
2. SHOULDER STAKES are used to indicate the inside edge of the roadway shoulders. These stakes are set opposite each center-line stake.
3. REFERENCE HUBS, as the name implies, are used to reference other stakes or to aid in establishing or reestablishing other stakes.
4. SLOPE STAKES mark the intersection of side slopes with the natural ground surface. They indicate the earthwork limits on each side of the center line.
5. RIGHT-OF-WAY STAKES indicate the legal right of passage and outmost bounds of construction.
6. GRADE STAKES indicate required grade elevations to the construction crews. During the final grading stage of construction, hubs called "blue tops" are used in lieu of stakes. The blue

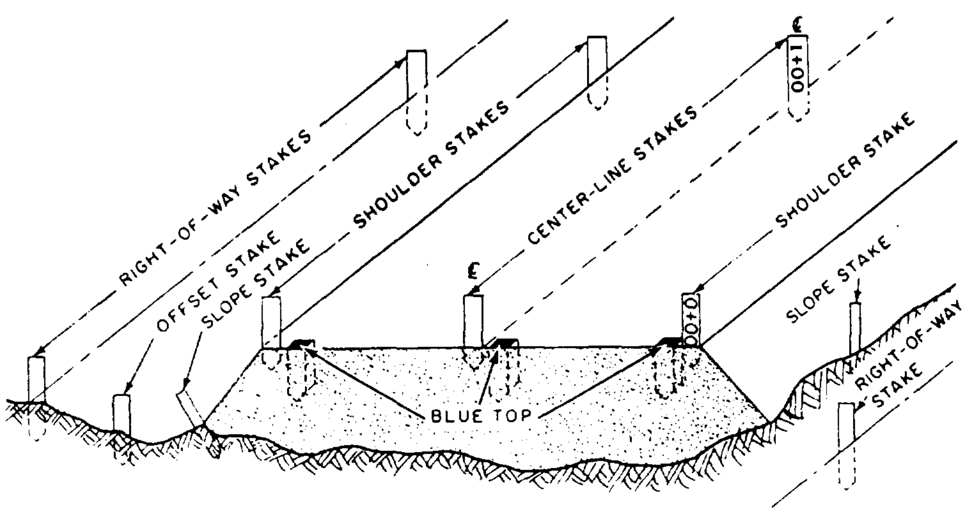


Figure 14-31.-Typical arrangement of various hubs and stakes on a road section (final grading).

tops are driven so that the top of the hub is set at the required grade elevation.

7. GUARD STAKES are used to identify and protect hubs. The face of the stake is marked with station identification and is placed so that the stake faces the hub it identifies. Sometimes more than one guard stake will be used to protect a hub.

8. OFFSET STAKES may be additional stakes that are offset a known distance from other stakes that will likely be disturbed during construction. The offset stake is marked with the same information as the stake it offsets, and it is also marked to show the offset distance. Often, stakes will themselves be offset a known distance from their true location. This eliminates the requirement for additional stakes.

CENTER-LINE LAYOUT.— The first major step in highway construction is usually the rough grading; that is, the earthmoving that is required to bring the surface up to, or down to, the approximate elevation prescribed for the subgrade. The SUBGRADE is the surface of natural soil, or the place where the pavement will be laid. The subgrade elevation, therefore, equals grade (finished surface) elevation minus the thickness of the pavement.

In rough grading, the equipment operators are usually guided by grade stakes that are set along the center line by the transit-tape survey party at center-line stations. The center-line stations (stakes) are usually set at intervals of 100 ft or more on straight-line stretches and intervals of 50 ft or less on roads with horizontal and vertical curvatures. On a small-radius, street-corner curve, a center-line hub or stake might be set at the center of the circle of which the curve is a part. This is done so the construction crew may outline the curve by swinging the radius with the tape. Reference stakes or hubs are also set on one or both sides of the center line to permit reestablishment of the center line at any time.

Each center-line stake is marked with the vertical depth of cut or fill required to bring the surface to grade elevation. The surveyor must indicate the station markings and the cut and fill directions on stakes. Let's look at the stakes on the center line of the road-building job. The starting point is the first station in the survey;

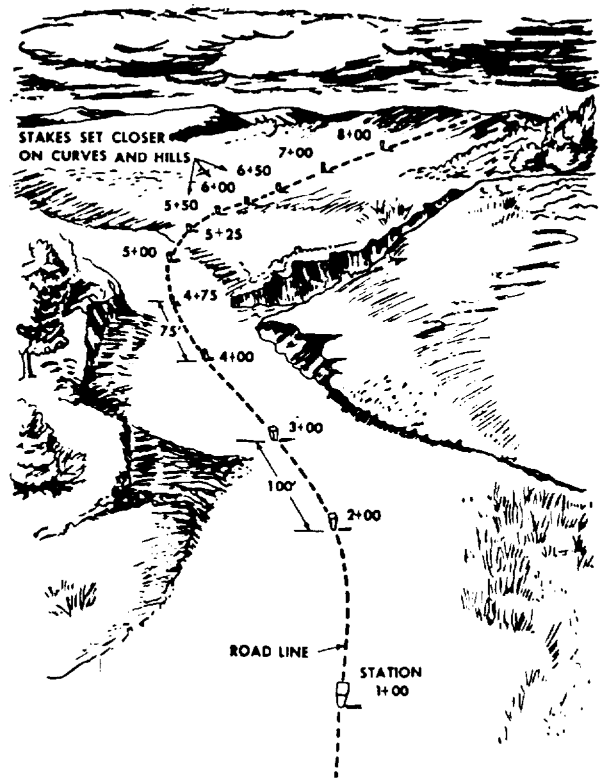


Figure 14-32.-Station markings.

this station is numbered 0 + 00. The next station is normally 100 ft farther and is marked 1 + 00; the third station is another 100 ft farther and is marked 2 + 00; and so on. On sharp curves on rough ground, the stakes may be closer together. (See fig. 14-32.) Generally, the station markings face the starting point. The mark ℄, which is also on the side facing the starting point, is used to indicate that the stake is a center-line stake.

A cut is designated by the letter C, and the fill is indicated by the letter *F*. Numerals follow the letters to indicate the amount that the ground should be cut or filled. The symbol C– 1^{5} indicates that the existing ground should be cut 1.5 ft, as measured from the reference mark. During rough grading, the cut and fill are generally carried just up to the nearest half foot; exact grade elevations are later marked with hubs (blue tops). The mark ⊻ is called a crowfoot. The apex of the V indicates the direction of the required change in elevation; so a cut is indicated by ⊻, and a fill is indicated by ⊼ . In some cases, surveyors mark the grade stake only with a negative or a positive number and the crowfoot, indicating the cut or fill.

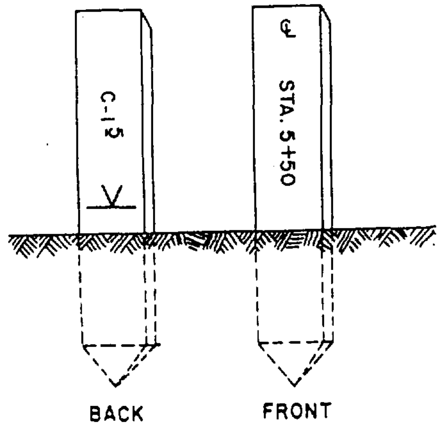


Figure 14-33.—Cut stake.

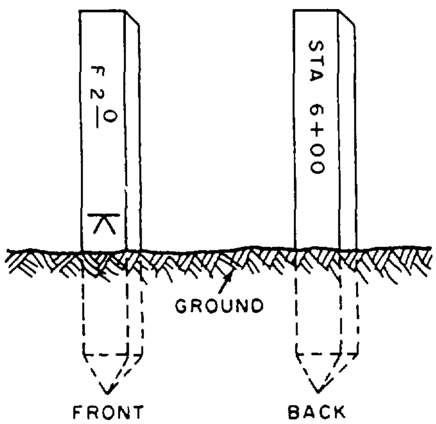


Figure 14-34.-Fillstake (not on centerline).

Figure 14-33 shows a cut stake that also happens to be a center-line marker. Note that station mark is written on the front of the stake and the construction information on the back. On grade stakes other than the center-line stakes, the construction information should be written on the front and the station marked on the back.

The stake shown in figure 14-34 indicates that fill operations are to be performed. The letter *F* at the top of the stake stands for fill. The numerals $2^{\underline{0}}$ indicate that 2 ft of fill are required to bring the construction up to grade.

Some stakes indicate that no cutting or filling is required. Figure 14-35, for example, shows a grade stake that is on the proper grade and also is a center-line stake. The word *GRADE* (or *GRD)* is on the back of the stake, and the crowfoot mark may not be indicated; some surveyors prefer to use a crowfoot mark on all grade stakes. If this

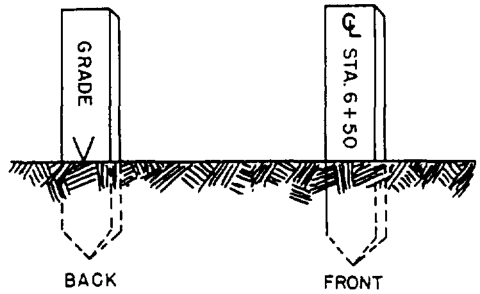


Figure 14-35.-Stake on proper grade.

grade stake is not a center-line stake, the GRD mark will be written on the front of the stake.

SETTING GRADE STAKES.— GRADE STAKES are set at points having the same ground and grade elevation. They are usually set after the center line has been laid out and marked with hubs and guard stakes. They can be reestablished if the markers are disturbed. Elevations are usually determined by an engineer's level and level rod. One procedure you can use for setting grade stakes is as follows:

1. From BMs, turn levels on the center-line hubs or on the ground next to a grade stake at each station.
2. Reduce the notes to obtain hub-top or ground elevation.
3. Obtain the finished grade elevation for each station from the construction plans.
4. Compute the difference between finished grade and the hub or ground elevation to determine the cut or fill at each station.
5. Go back down the line and mark the cut or fill on each grade stake or guard stake.

The elevations and the cuts or fills may be recorded in the level notes, or they may be set down on a construction sheet, as explained later in this chapter.

Another procedure may be used that combines the method listed above so that the computations may be completed while at each station; then the cut or fill can be marked on the stake immediately.

As before, levels are run from BMs; the procedure at each station is as follows:

1. Determine the ground elevation of the station from the level notes to obtain HI.
2. Obtain the finished grade for the station from the plans.

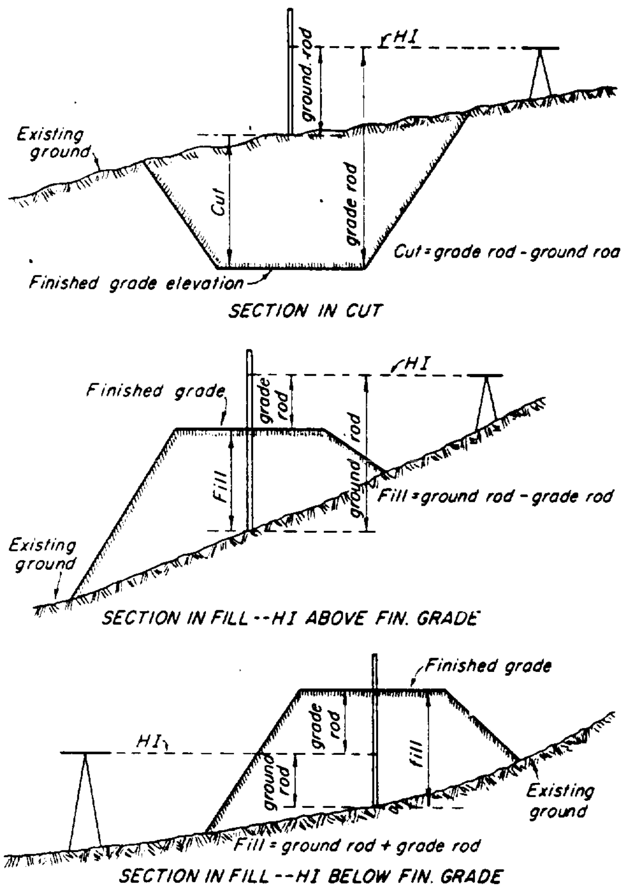


Figure 14-36.-Determining cut or fill from grade rod and ground rod.

3. Compute the difference between the HI and finished grade; this vertical distance is called grade rod.

4. Read a rod held on the hub top or ground point for which the cut or fill is desired. This rod reading is called ground rod.

5. Determine the cut or fill by adding or subtracting the grade rod and the ground rod, according to the circumstances, as shown in figure 14-36.

6. Mark the cut or fill on the stake.

During the final grading, you will most likely be working with hubs called BLUE TOPS (fig. 14-31). These hubs are driven into the ground until the top is at the exact elevation of the finished grade as determined by the surveying crew. When the top of the stake is at the desired finish grade elevation, it is colored with blue lumber crayon (keel) to identify it as a finished grade stake. Other colors may be used, but be consistent and use the same color keel throughout the project so as not to confuse the Equipment Operators. Blue tops are normally provided with a guard stake to avoid displacement during construction work. The guard stake usually shows the station and the elevation of the top of the hub. The elevation and station markings may be required only at station points; otherwise, all that is needed is the blue top and the guard stake with flagging.

The procedure for setting blue tops lends itself primarily to final grading operations. It is carried out as follows:

1. Study construction plans and center-line profiles for each station to determine (1) the exact profile elevation and (2) the horizontal distance from center line to the edge of the shoulder.

2. Measure the horizontal distance from the center line to the shoulder edge at each station, and drive a grade stake at this point on each side. Sometimes it is advisable to offset these stakes a few feet to avoid displacement during construction.

3. Set the top of the stake even with the grade elevation, using both the level and the rod. This is accomplished by measuring down from the HI a distance equal to the grade rod (determined by subtracting grade elevation from the HI). The target on the rod is set at the grade-rod reading; the rod is held on the top of the stake; and after a few trials, the stake is driven into the ground until the horizontal hair of the level intersects the rod level indicated by the target. Color the top of a stake with blue crayon (keel).

4. Where the tops of stakes cannot be set to grade because grade elevation is too far below or above the ground line, set in ordinary grade stakes marked with the cut or fill as in rough grading. However, for final grading, it is usually possible to set mostly blue tops.

Where grade stakes cannot be driven, for example, in hard coral or rock areas, use your ingenuity to set and preserve grade markings in a variety of conditions. Markings may often be made on the rock itself with a chisel or with a keel.

SETTING SLOPE STAKES.– SLOPE STAKES are driven at the intersection of the ground and each side slope or offset a short distance; they indicate the earthwork limits on each side of the center line. The minimum areas to be cleared and grubbed extend outward about 6 ft from the slope stakes.

Refer back to figure 14-31 and take a close look at the position of the slope stakes. The horizontal distance of a slope stake from the center line varies, and to determine what it is, you must know three things.

1. The width of the roadbed, including widths of shoulders and ditches, if any
2. The side-slope ratio (expressed in units of horizontal run in feet per foot of vertical rise or fall)
3. The difference in elevation between the grade for the road and the point on the natural ground line where the slope stake will be set

In figure 14-37, view A, d is the horizontal distance from the center line to the slope stake, W/2 is the horizontal distance from the center line to the top of the slope, h is the difference in elevation between the finished grade and the ground at the slope stake, ands is the slope ratio. The product of h x s gives the run of the slope; that is, the horizontal distance the slope covers. The horizontal distance (d) of the slope stake from the center line, then, equals the sum of W/2 plus hs. For example, suppose that W/2 is 20 ft, h is 10 ft, and the bank is a 4:1 slope. Then

$$hs = 10 \times 4, \text{ or } 40$$

and

$$d = 20 \text{ ft} + 40 \text{ ft, or } 60 \text{ ft.}$$

In practice, you may have to take other factors into account, such as transverse slope or the crossfall of the pavement (sometimes called the crown), ditches, and so on. In figure 14-37, view B, for example, there is a crossfall (h=) across W/2 so that the run (horizontal distance covered) of the bank ($h_b s$) is the product of s x h_b instead of hs, as in figure 14-31, view A. The crossfall is usually constant and may be obtained from the typical design sect ion shown on the plans.

Figure 14-37, view C, shows a cut section in which W/2 varies with crossfall, side slope, ditch depth, and back slope. For example, assume that the distance from the center line to the beginning of the side slope is 20 ft, that the cross fall totals 1 ft, that ditch depth is 1.5 ft, and that both the side slope and back slope ratios are 2:1. The distance W/2, then, comprises horizontal segments as follows:

1. From the center line to the top of the slope which is 20 ft

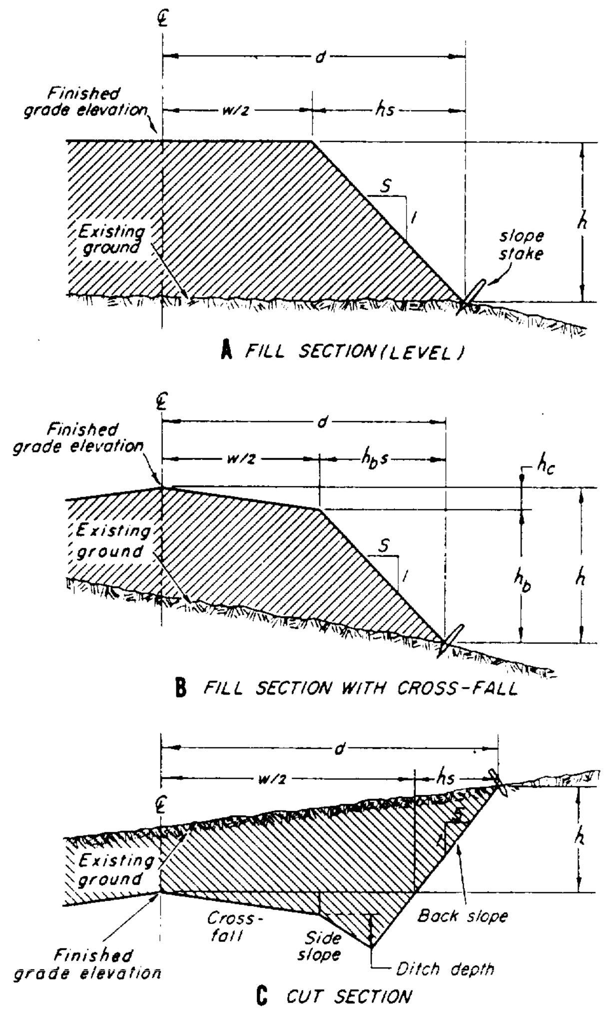


Figure 14-37.-Determining slope stake location (distance from center line) for a proposed roadway.

2. Then to the ditch flow line, which equals the product of slope ratio (2) times ditch depth (1.5), or 3 ft
3. Then to the point on the back slope that is level with the finished center line, which equals slope ratio (2) times difference in elevation; that is, crossfall plus ditch depth,

$$2(1 + 1.5), \text{ or } 5 \text{ ft.}$$

The total distance, W/2, then, is the sum of

$$20 + 3 + 5, \text{ or } 28 \text{ ft.}$$

SLOPE-STAKE PARTY PROCEDURE.— Slope stakes are usually set with an engineer's or automatic level, a level rod, and a metallic or nonmetallic tape. In rough terrain, a hand level is generally used instead of an engineer's level.

If the engineer's level is used, three crew members are generally employed for fieldwork; they are the instrumentman, the rodman, and one person to hold the zero end of the tape at the center line. When a hand level is used, two persons can take care of the job—the instrumentman also holds the zero end of the tape and is positioned at the center-line station as the rod reading is taken. The procedure followed is a trial and error process. Under field conditions, the rodman is at times as much as 200 or 300 ft away from the instrumentman. If power equipment is operating nearby or a wind is blowing, oral instructions cannot be given to the rodman about where to take trials shots; in fact, often there. is not a clear view of the ground slope at the station being worked.

Consequently, the rodman must know as much as the instrumentman does about the theory and practice of setting slope stakes. The speed and efficiency of the party depend on the rodman more than on any other member. The rodman must be constantly mentally alert.

The most practical field procedure requires that the rodman know the value of W/2 and of s (the slope ratio). This is not difficult, since these values are usually constant for several stations, and the rodman can be informed when they change. A typical procedure for setting slope stakes is as follows:

1. The instrumentman computes the center-line cut or fill, using the HI, finished grade, and the existing ground elevation. Refer back to figure 14-36.
2. The instrumentman calls or signals the center-line cut or fill to the rodman.
3. The rodman mentally computes the approximate value of d by multiplying h x s and adding W/2. He pulls the tape taut while holding the tape at the computed distances.
4. Noting the approximate rise or fall of the ground, the rodman adjusts the approximate value of d, moves to the d point, and sets up the rod for a trial shot.
5. The instrumentman quickly calculates the cut or fill at this point and calls the value to the rodman.
6. The rodman compares this with the estimated cut or fill. He should be fairly close and should know at once whether to move toward, or away from, the center line. Having a much shorter distance over which to estimate ground slope, he again estimates new cut or fill and hs + W/2, and moves the rod to the new d value.

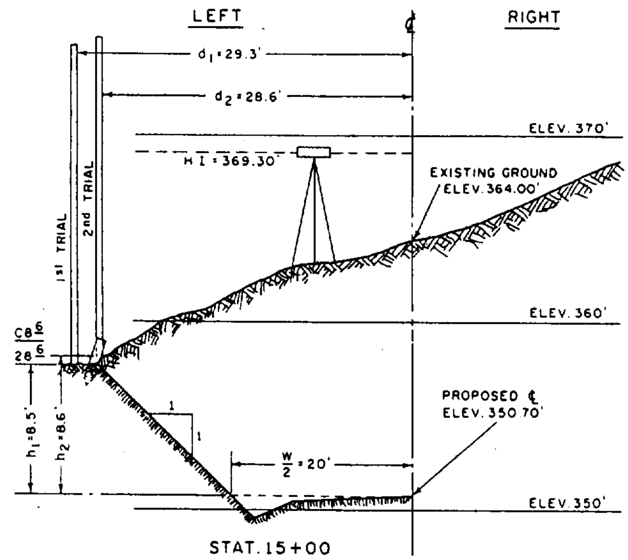


Figure 14-38.-Setting slope stakes.

7. The instrumentman again gives the cut or fill; if the value checks, the rodman calls or signals back the cut or fill and the distance.

8. The instrumentman quickly checks the two values mentally, and if the values are correct, records the values in the field book, signaling "Good" to the rodman.

9. The rodman marks and drives the stake.

With practice and on fairly smooth ground, a good rodman will seldom miss the first trial by more than 0.2 ft vertically and will, quite often, hit the correct value on the first trial.

Figure 14-38 shows the application of these procedures to an actual situation. The following data are known for this slope-stake stakeout:

1. The station is 15 + 00.

2. The W/2 (from the typical design section) is 20 ft.

3. The slope ratio is 1:1; therefore, s = 1.

4. The existing ground elevation at the center line (from the previously run profile) is 364.00 ft.

5. The HI is determined to be 369.30 ft at that setup.

The steps taken by the instrumentman and the rodman are as follows:

1. The instrumentman determines the center-line cut by subtracting 350.7 ft from 364.0 ft to get the cut, or 13.3 ft.

2. The rodman holds at the center line for a check. The rod should-read 369.3 (the HI) minus 364.0, or 5.3 ft.

3. The instrumentman calls to the rodman, "Cut 13.3 feet."

4. The rodman computes

$$d= 20+(1 \times 13.3) = 33.3$$

as he walks to the left.

5. As he approaches about 30.0 ft from the center line, he estimates that the ground has a fall of 4 ft. Therefore, he computes the new cut as

$$13.3 - 4.0, \text{ or } 9.3 \text{ ft.}$$

This means a new d of

$$20 + (1 \times 9.3) = 29.3 \text{ ft.}$$

6. The rodman sets up the rod 29.3 ft from the center line, as measured by metallic tape.

7. The instrumentman reads 10.1 on the rod and computes the new cut as

$$369.3 - (350.7 + 10.1), \text{ or } 8.5 \text{ ft.}$$

NOTE: Here you can also use the grade rod and ground rod values as explained earlier; the new cut then will be

$$18.6 - 10.1 = 8.5 \text{ ft.}$$

Refer back to figure 14-36.

8. The instrumentman calls, "Cut 8.5," to the rodman.

9. The rodman computes

$$d = 20 + (1 \times 8.5) = 28.5 \text{ ft.}$$

He knows, therefore, that 29.3 ft from the center line is too far out.

10. Figuring that the ground rises about 0.1 ft between 29.3 left and 28.5 left, the rodman calculates that the more nearly correct cut will be

$$8.5 + 0.1, \text{ or } 8.6 \text{ ft.}$$

11. By using this cut, the rodman calculates the new d as

$$20 + (1 \times 8.6),$$

and sets the rod at 28.6 ft left.

12. The instrumentman reads 10.0 on the rod and computes the new cut as

$$369.3 - (350.7 + 10.0) = 8.6 \text{ ft.}$$

13. The instrumentman calls, "Cut 8.6," to the rodman.

14. The rodman sees that the actual cut of 8.6 ft agrees with his estimated cut of the same, and calls, "Cut 8.6 at 28.6," to the instrumentman.

15. The instrumentman checks

$$d = 20 + (1 \times 8.6) = 28.6,$$

signals the rodman, "Good," and makes the following entry into the field book:

$$\frac{C8^6}{28}$$

16. The rodman marks a stake with 15 + 00 and $C8^6$ and drives it in the ground at 28.6 ft left.

More often, slope stakes may be set by using a hand level. Their distances out are generally measured to the nearest half or tenth of a foot. If a slope stake is placed in an offset position, the offset distance is also marked on the stake so the equipment operator is not confused about its actual location. Slope stakes are seldom used in areas requiring less than 2 ft of cut or fill.

Curb and Gutter Stakeout

For a thoroughfare that will have a curb and gutter, these items are usually constructed before the finish grading is done. The curb constructors obtain their line and grade from offset hubs like those described previously. Guided by these, the earthmovers make the excavation for the curb, the formsetters set the forms, and the concrete crew members pour, finish, and cure the curb.

Once the curb has been constructed, shaping the subgrade to correct subgrade elevation and laying the pavement to correct finished grade is simply a matter of measuring down the correct distance from a cord stretched from the top of one curb to the top of the curb opposite.

Pavement Stakeout

Pavement stakeout will depend on the type of paving equipment used. Steps in the method commonly used for paving concrete highways are as follows:

1. Set a double line of steel side forms, equipped with flanges that serve as tracts for traveling paving equipment.
2. Fill the space between the forms with concrete poured from a concrete paving machine (commonly called just a paver).
3. Spread the' concrete with a mechanical spreader that travels on the flanges of the side forms.
4. Finish the surface with a finisher, a machine that also travels on the side forms.

The line-and-grade problem—that is, the layout or stakeout problem—consists principally of setting the side forms to correct line with the upper edges of the flanges at the grade prescribed for the highway. If the finished grade shown on the plans is the center-line grade, then the forms are set with tops at the center-line grade less the crossfall. If the design elevations are shown for points other than those on the center line, the form elevation is related to the design points as indicated by the typical section.

Stakeout maybe done by setting a line or lines of offset hubs, as previously described. Sometimes, however, a line of hubs is driven along the line the forms will occupy and driven to grade elevation less the depth of a side form. The forms are then set to the line and the grade by simply placing them on the hubs.

Concrete paving is also done by the slip form method in which, instead of a complete double line of forms, a sliding or traveling section of formwork is an integral part of the spreading and finishing machinery. The machinery is kept on line and the pavement finished at grade by a control device or devices. The line control device usually follows a wire stretched between rods that are offset from the pavement edge.

Forms are not usually used in asphalt paving. Asphalt paving equipment, in general, is designed to lay the pavement at a given thickness, following the fine-graded subgrade surface. The manner in which a given piece of equipment is kept on line varies, and the stakeout for equipment varies accordingly.

STRUCTURAL SURVEYS

A STRUCTURAL survey is one that is part of the chain of human activities that will bring a structure, such as a building, a bridge, or a pier into existence.

Earthwork

As when a highway is built, the first major step in the construction of a structure is usually the rough grading—that is, the earthmoving needed to bring the surface of the site up to, or down to, the approximate specified rough grade.

The stakeout for rough grading is commonly done by the GRID method. The area to be graded, which is shown, along with the prescribed finish grade elevation on the site or plot plan is laid off in 25-, 50-, or 100-ft grid squares. The elevation at each corner point is determined; the difference between that and the prescribed grade elevation is computed; and a grade stake is marked with the depth of cut or fill; then the stake is driven into the ground at the point.

Building Stakeout

If the structure is a building, the next major step after the rough grading is the building stakeout; that is, the locating and staking of the main horizontal control points of the building. These are usually the principal corner points plus any other points of intersection between building lines.

The procedure followed varies with circumstances. Figure 14-39 shows a simple building

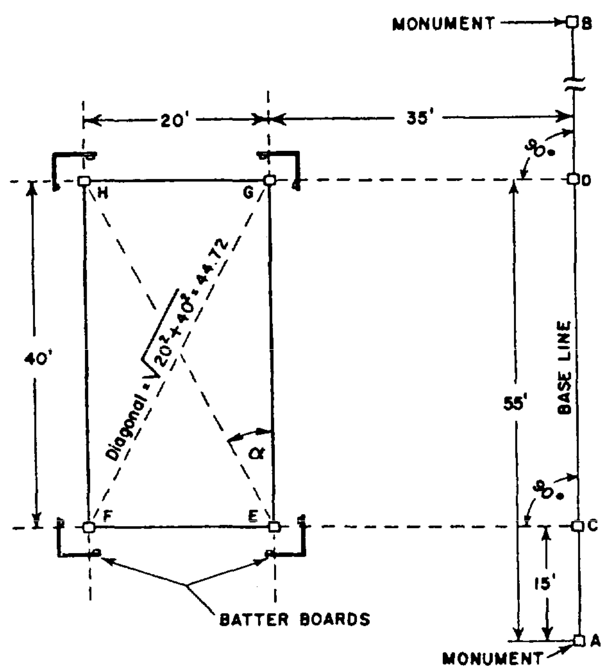


Figure 14-39.-Building stakeout.

stakeout. This site plan shows that the building is to be a 40- by 20-ft rectangular structure, located with one of the long sides parallel to, and 35 ft away from, a base line. The base line is indicated at the site and on the plans by Monuments A and B.

One of the short sides of the building will lie on a line running from C, a point on AB 15 ft from A, perpendicular to AB, The other short side will lie on a similar line running from D, a point on AB 40 ft from C and, therefore, 40 + 15, or 55 ft from A, perpendicular to AB.

The steps in the stakeout procedure would probably be as follows:

1. Set up the transit at Monument A; train the telescope on a marker held on a Monument B; then have the hubs driven on the line of sight, one at C 15 ft from A, the other at D 55 ft from A and 40 ft from C.

2. Shift the transit to C, train on B, match the zeros, and turn 900 left. Measure off 35 ft from C on the line of sight and drive a stake to locate E. Measure off 55 ft from C (or 20 ft from E) and drive another stake to locate F.

3. Shift the transit to D and repeat the procedure described in Step 2 to locate and stake points G and H.

THE ACCURACY OF A RECTANGULAR STAKEOUT CAN BE CHECKED BY MEASURING THE DIAGONALS OF THE RECTANGLE. The diagonals should, of course, be equal. You can determine what the correct length of each diagonal should be by applying the Pythagorean theorem, as shown in figure 14-39.

For a large rectangle, checking the accuracy of the stakeout by angular measurement with the transit may be more convenient. For example: You can determine the correct size of angle GEH, (let's call it a) in figure 14-39 by a convenient right-triangle solution, such as

$$\tan \alpha = 20/40 = 0.50000.$$

The angle with tangent 0.50000 measures (to the nearest minute) 26°34′. Therefore, angle FEH should measure

$$90°00' - 26°34', \text{ or } 63°26'.$$

The corresponding angles at the other three corners should have the same dimensions. If the sizes as actually measured vary at any corner, the stakeout is inaccurate.

Remembering the angles may be necessary to obtain the correct angular precision for the lengths of the lines being checked.

BATTER BOARDS are suitable marks placed for use as references or guides during the initial excavation and rough grading of a building construction and/or a sewer line stakeout. They are more or less temporary devices that support the stretched cords that mark the outline and grade of the structure.

Batter boards consist of 2- by 4-in. stakes driven into the ground. Each stake has a crosspiece of 1- by 6-in. lumber nailed to it. The

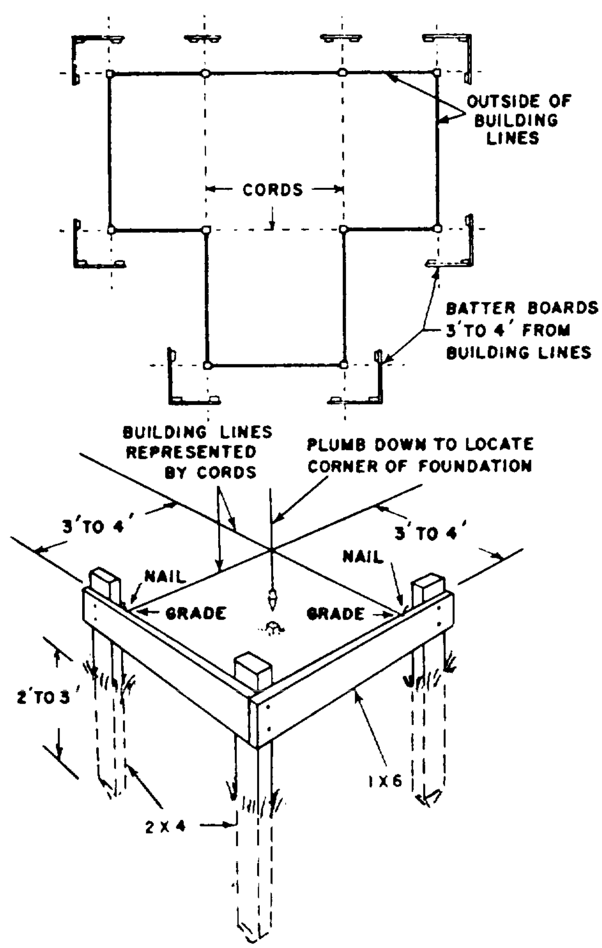


Figure 14-40.-Batter boards.

stakes are driven about 3 to 4 ft away from the building line where they will not be disturbed by the construction. They are driven far enough apart to straddle the line to be marked. Note in figure 14-40, only three stakes are driven on outside corners because one of them is a common post for two directions. The length of the stakes is determined by the required grade line. They must be long enough to accept the 1- by 6-in, crosspiece to mark the grade. The 1- by 6-in, crosspiece is cut long enough to join both stakes and is nailed firmly to them after the grade has been established. The top of the crosspiece becomes the mark from which the grade will be measured. All batter boards for one structure are set to the same grade or level line. A transit is used to locate the building lines and to mark them on the top edge of the crosspiece. A nail is driven at each of these marked points, or a V notch is carved at the top outer edge of the crosspiece towards the marked point and the nail is driven on the outer face of the board.

When a string is stretched over the top edge of the two batter boards and is held against the nails or against the bottom of the notch, the string will define the outside building line and grade elevation.

Sometimes a transit is not available for marking the building line on the batter boards, but the corner stakes have not been disturbed. A cord is stretched over two opposite batter boards, and plumb bobs are held over the corner stakes; then the building line can be transferred to the batter boards. The cord is moved on each batter board until it just touches both plumb bob strings. This position of the cords is marked, and nails are driven into the top of the batter boards.

Batter boards are set and marked as follows:

1. After the corner stakes are laid out, 2-by 4-in. stakes are driven 3 to 4 ft outside of each corner. These are selected to bring all crosspieces to the same elevation.

2. These stakes are marked at the grade of the top of the foundation or at some whole number of inches or feet above or below the top of the foundation. A level is used to mark the same grade or elevation on all stakes.

3. One- by six-in. boards are nailed to the stakes so the edge of the boards is flush with the grade marks.

4. The prolongation of the building lines on the batter boards is located by using a transit or by using a line and plumb bob.

5. Either nails are driven into the top edges of the batter boards or the boards are notched to mark the building line.

UTILITIES STAKEOUT

UTILITIES is a general term applied to pipelines, such as sewer, water, gas, and oil pipelines; communications lines, such as telephone or telegraph lines; and electric power lines.

Aboveground Utilities

For an aboveground utility, such as a pole-mounted telephone, telegraph, or power line, the survey problem consists simply of locating the line horizontally as required and marking the stations where poles or towers are to be erected. Often, the directions of guys and anchors maybe staked as well, and sometimes pole height for vertical clearance of obstructions is determined.

Underground Utilities

For an underground utility, you will often need to determine both line and grade. For pressure lines, such as water lines, it is usually necessary to stake out only the line, since the only grade requirement is that the prescribed depth of soil cover be maintained. However, staking elevations may be necessary for any pressure lines being installed in an area that (1) is to be graded downward or (2) is to have other, conflicting underground utilities.

Gravity flow lines, such as storm sewer lines, require staking for grade to be sure the pipe is installed at the design elevation and at the gradient (slope) the design requires for gravity flow through the pipe.

Grade for an underground sewer pipe is given in terms of the elevation of the invert. The INVERT of the pipe is the elevation of the lowest

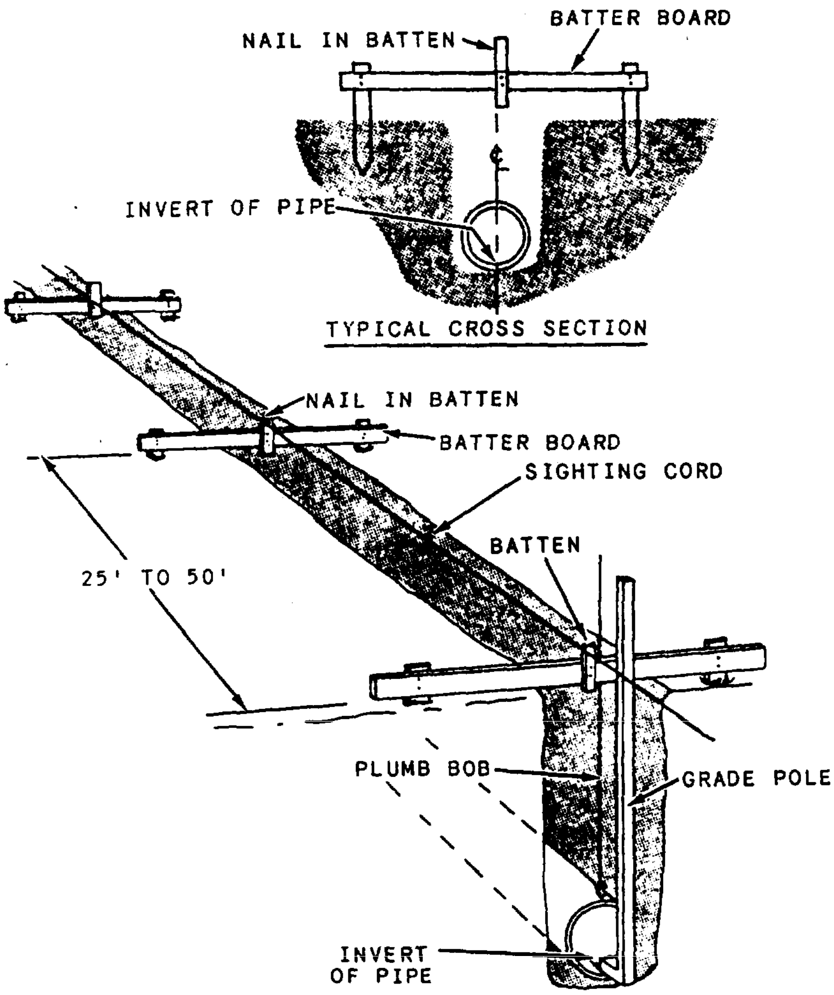


Figure 14-41.-Use of batter boards (with battens) for utility shakeout.

part of the inner surface of the pipe. Figure 14-41 shows a common method of staking out an underground pipe. Notice that both alignment and elevation are facilitated by a line of batter boards and battens (small pieces of wood) set at about 25- to 50-ft intervals. The battens, nailed to the batter boards, determine the horizontal alignment of the pipe when placed vertically on the same side of the batter boards and with the same edges directly over the center line of the pipe. As the work progresses, you should check the alignment of these battens frequently. A sighting cord, stretched parallel to the center line of the pipe at a uniform distance above the invert grade, is used to transfer line and grade into the trench. The center line of the pipe, therefore, will be directly below the cord, and the sewer invert grade will be at the selected distance below the cord. A MEASURING stick, also called a grade pole, is normally used to transfer the grade from the sighting cord to the pipe (fig. 14-41). The grade pole, with markings of feet and inches, is placed on the invert of the pipe and held plumbed. The pipe is then lowered into the trench until the mark on the grade pole is on a horizontal line with the cord.

Figure 14-42 shows another method of staking out an underground sewer pipe without the use of battens. Nails are driven directly into the tops of the batter boards so that a string stretched tightly between them will define the pipe center line. The string or cord can be kept taut by wrapping it around the nails and hanging a weight

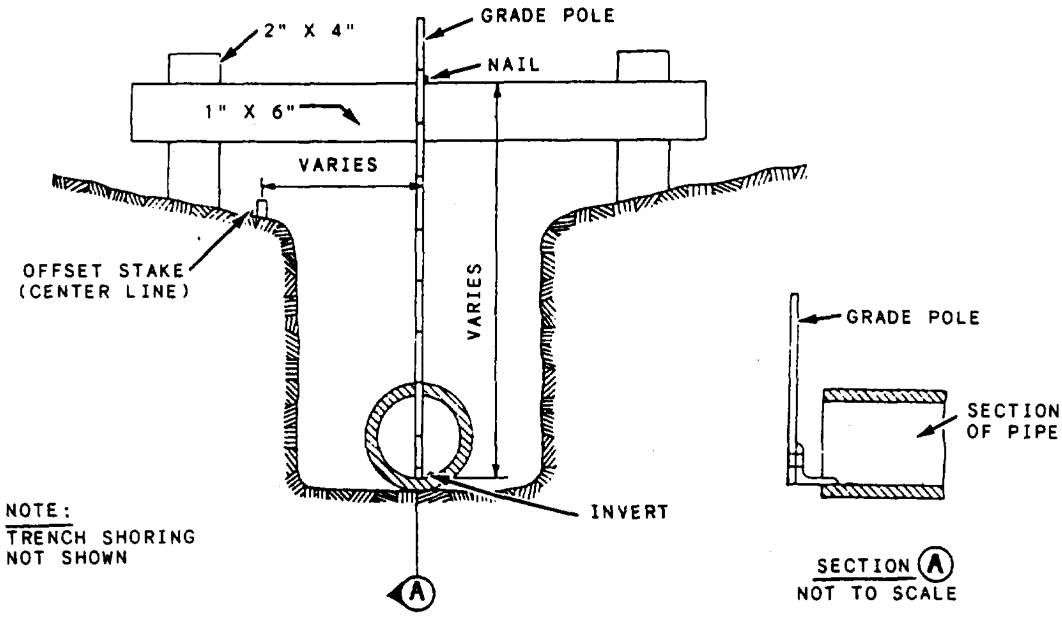


Figure 14-42.-Batter boards (without battens) for utility stakeout.

on each end. Similarly, the string (or cord) gives both line and grade.

AS-BUILT SURVEY

A finished structure seldom corresponds exactly to the original plans in every detail. Unexpected, usually unforeseeable difficulties often make variations from the plans necessary—or, occasionally, variations may occur accidentally that are economically unfeasible to correct.

The purpose of an AS-BUILT SURVEY is to record these variations. The as-built survey should begin as soon as it becomes feasible—meaning that the actual horizontal and vertical locations of features in the completed structure should be determined as soon as the features are erected.

At times, variations from the original plans are recorded on new tracings of the working drawings, on which as-built data are recorded in the place of the original design data when the two happen to differ. Sometimes, reproductions of the original drawings are used with variations recorded by crossing out the original design data and writing in the as-built data.

In either case, the term *as-built survey,* together with the date of revision, is written in, or near, the title block.

CONSTRUCTION-SITE SAFETY

WARNING

A survey party working at a construction site is always in a dangerous situation.

Where blasting or logging is going on, inform the powder crew or logging crew of the location of the area in which surveyors are working. Also, instruct the individual crew members of the survey party to be on the alert at all times—particularly to listen for the warning signal given by a crew using powder to set off a charge or a logger felling a tree.

When surveying near highways, railroads, or airstrips, use red flagging generously unless you are working in a combat area. Place flagging on the legs of your surveying equipment and at a few places along the tape. Put flags on rods and range poles. Attach some flagging to your hat and also to the back of your shirt or jacket.

Think constantly of personal safety when working near heavy construction equipment. Let the equipment operators know when surveyors are in the vicinity. Also, alert all members of the surveying crew because an equipment operator's vision is often obscured by dust or by the equipment itself.

When ascending steep, rocky slopes, do not climb directly behind another crew member. If the crew member were to accidentally fall, loosen a rock, or drop something, it could mean serious injury to anyone directly below the crew member.

EXCAVATIONS

WARNING

When your work involves excavation, you should observe definite precautions to prevent accidents.

To avoid slides or cave-ins, support the sides of the excavations 5 ft or more deep by substantial bracing, shoring, or sheet piling if the sides are steeper than the angle of repose. The ANGLE OF REPOSE is the maximum angle at which material will repose without sliding. Trenches in partly saturated or otherwise highly unstable soil should be stabilized with vertical sheet piling or suitable braces. Foundations of structures adjacent to excavations should be shored, braced, or underpinned as long as the excavation remains open. Excavated or other material should not be allowed to accumulate closer than 2 ft from the edge of an excavation. In a traffic area use barricades, safety signs, danger signals, red lights, or red flagging on at least two sides.

Do not enter a manhole until you are certain that it is free from dangerous gases. Do not guess. If there is any question at all as to whether a sewer is free of gas, wait for clearance from a competent authority. If necessary, provide first for thorough ventilation. Do not smoke in manholes; and if illumination is required, use only a safety flashlight or lantern.

Avoid contact with ALL ELECTRIC wiring. Never throw a metal tape across electric wires; if you must chain across wiring, do it by breaking chain. Avoid placing yourself so that you might fall across wiring in the event of an accident.

When walking, stay at least 2 feet away from the edge of a vertical excavation. Near thoroughfares or walkways, excavations should have temporary guardrails or barricades; and if permissible, depending on combat conditions, red lights or torches should be kept alongside from sunset to sunrise.

TREE CLIMBING

Before climbing a tree, be sure it is safe to climb, and carefully cheek the condition of the branches on which you are likely to stand. Different kinds of wood vary greatly in strength. Oak, hickory, and elm trees that have strong, flexible wood are safer for climbing than trees such as poplar, catalpa, chestnut, or willow, which have soft or brittle wood. Limbs of all trees become brittle at low temperature—meaning that they break more easily in cold weather than they do in warm. Dead branches or those containing many knots or fungus growths are usually weak.

When standing on a limb, have your feet as close to the parent trunk as possible. Climb with special care when limbs are wet or icy. Wear goggles when working in bushy trees; they may prevent an eye injury.

WARNING

Before climbing a tree, be sure there are no overhead wires passing through its foliage. If you MUST take a position in a tree within reach of live wire, place some sort of insulating safety equipment between yourself and the wire. DO NOT allow tree limbs to contact live wires because moisture in a limb may cause a short circuit.

If you require cutting tools to clear a working space in a tree, haul them up with a handline, and lower them by the same device. Tools should never be thrown up into a tree or down onto the ground.

UNDERGROUND AND OVERHEAD LINES

If a structure has an access opening and is below the street, such as a manhole or a transformer vault, it should be protected by a barrier or other suitable guard when the cover to the access opening is removed.

CROSSING ICE

Do not cross ice unless, and until, you are certain it will support your weight.

Both the thickness and the nature of ice are important in determining its carrying capacity.

Because part of the supporting power of ice is derived from the water below it, a layer of ice that is in contact with the water surface is safer than one that has no contact with the water surface.

An ice layer usually becomes thinner over current, near banks of streams or lakes, over warm springs, and over swampy ground. Rotten ice that can be identified by its dull color and honeycomb texture has little supporting power.

WORK SAFELY—STRESS SAFETY